

**DESIGNING CONCEPTUAL CHANGE ACTIVITIES FOR THE PHYSICS
CURRICULUM: THE CYPRUS PARADIGM**

by

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I declare that **Designing conceptual change activities for the Physics Curriculum: The Cyprus paradigm** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

SIGNATURE
(Mr **A S Kapartzianis**)

15-05-2012
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ABSTRACT

This study is a two part research project that describes and evaluates the efforts of the researcher to bring change in Cyprus' educational system, in the field of simple electric circuits. The objective of the first part was the assessment and evaluation of Cypriot STVE students' perceptions about simple electric circuits. The objective of the second part was to measure the effectiveness that conceptual change model-based instructional activities designed by the researcher had on changing students' misconceptions about simple electric circuits towards scientifically accepted ideas. Transformative mixed methods research design was used consisting mainly from an one-group pre-test post-test design with **Determining and Interpreting Resistive Electric Circuits Concepts Test 1.2** as a research instrument, while interviews and field notes were used for triangulation. The findings showed that there was a significant improvement in students' understanding of simple electric circuit concepts that were taught using conceptual change model-based instructional activities.

Key words: Conceptual change, Conceptual Change Model Based Instruction, Conceptual Change Model Based instructional activities, misconceptions, simple electric circuits, Secondary Technical and Vocational Education.

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LIST OF ABBREVIATIONS

CCM	Conceptual Change Model
CCMBI	Conceptual Change Model Based Instruction
DIRECT	Determining and Interpreting Resistive Electric Circuits Concepts Test
MOEC	Ministry Of Education and Culture
STVE	Secondary Technical and Vocational Education
TIMSS	Trends in International Mathematics and Science Study

CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Trends in International Mathematics and Science Study (TIMSS) survey results showed that the vast majority of Cypriot students (approximately 70%) consider Physics (and Physical Sciences in general) as a popular or very popular course. Indeed, this rate is one of the highest among the countries TIMSS surveyed. But on the contrary, the average performance of Cypriot students was one of the lowest compared to the others. Therefore, although the attitudes of the majority of students were positive, performance hasn't followed the same direction (Beaton, Martin, Mullis, Gonzalez, Smith & Kelly, 1996).

A possible reason for this antithesis, could be that the existing Cypriot National Physics Curriculum remains to a great extent "traditional", dominated by the philosophy of "intellectualism" and emphasizes the learning of facts and the implementation of "classical scientific experiments" to illustrate a particular point. As also confirmed by Hake in his study of 1998 (Hake, 1998), students who were taught using the traditional curriculum tend to be outperformed by students who were taught using interactive engagement methods. Moreover, as students' performance is determined almost entirely from their scores in tests, it leads a lot of students to acquire only the knowledge that ensures success in the examinations, disregarding everything else (Educational Reform Committee, 2004).

Wieman and Perkins (2005) argue that in order to teach physics in a way that does not produce such dismal results for the typical student, a physics curriculum must be aimed at helping students develop and enhance their conceptual understanding which is regarded as one of the most important aspects of learning.

Researchers (Posner, Strike, Hewson, & Gertzog., 1982; Stepan, 1996; Hake, 1998; Alonso-Tapia, 2002) claim that helping students develop and enhance their conceptual understanding, requires a great deal of cognitive effort, an effort that only models of instruction using activities that foster conceptual change can achieve. In this study, the researcher in order to confirm this claim, designed conceptual change activities and measured their effectiveness at promoting students' conceptual change, and improving their conceptual understanding test score results.

1.2 BACKGROUND AND PROBLEM STATEMENT

During the last decades a series of observations and empirical research studies (Brumby, 1982; Clement, 1979; Driver, 1973; Driver & Easley, 1978; Driver, Squires, Rushworth & Robinson, 1994; Engelhardt & Beichner, 2004; Fredette & Clement, 1981; Gunstone & White, 1981; Osborne & Freyberg, 1985; Selman, Jaquette, Krupa & Stone, 1982) showed that students had significant difficulties in understanding, describing, interpreting and predicting natural phenomena. These difficulties were observed even among students that performed well on textbook problems (Reif, 1986; Champagne, Gunstone & Klopfer, 1983; Koumaras, 1989).

After further investigations it was found that the reason for these students' failures was not the absence of theories, but the persistence of *preconceptions*, preformed ideas and theories about how the natural world works, theories that students bring with them to the science class and stand as an obstacle to what students are expected to learn (Champagne *et al.*, 1983; Pfundt & Duit, 2006).

Chi and Roscoe (2002) differentiate two forms of prior conceptions: preconceptions that can be easily and readily revised through instruction, and *misconceptions*, preconceptions that are robust and highly resistant to change, even when not supported by observations.

Although the existence of students' prior conceptions has been detected in various fields of physics, a more coherent discussion of the issues can be presented when attention is focused on one field at a time. As our study will focus on the field of electricity, the subsequent discussion will focus on this field from now on.

Students' understanding of electricity concepts has been the object of study for many researchers in psychology and education. These studies were performed among young pupils (Osborne & Freyberg, 1985; Paraskeyas & Alimisis, 2007), high school students (Borges & Gilbert 1999; Koumaras, Psillos Valassiades & Evangelinos, 1990; Koltsakis & Pierratos, 2006) or even among university students (Engelhardt & Beichner, 2004).

The results of these studies showed that pupils, high school students, and even their teachers (Webb 1992, Wiles & Wright 1997), as well as practitioners (Borges & Gilbert 1999), share a number of misconceptions about electricity. These misconceptions were repeatedly observed in various countries, with people coming from different cultures that

have attended different educational systems (Shipstone *et al.* 1988).

But although all these evidence about students' conceptions has been accumulated over the years, in the development of science curricula the existence of the misconceptions about electricity concepts has usually either been ignored or inadequately considered (Fensham, 1980; Koumaras, Psillos, Valassiades & Evangelinos, 1990; Sencar & Eryilmaz, 2004).

The situation in Cyprus was until now more or less the same, despite piecemeal efforts for modernisation of the curriculum that have been made at times from the Cyprus Pedagogical Institute, an educational institution which was founded in 1972 with a mission, among others, to actively contribute to the compilation of analytical programmes (curriculum) for the schools of primary, secondary and tertiary education in Cyprus (Cyprus Pedagogical Institute, n.d.). The lack of focus on students' misconceptions and the absence of instructional activities that address these misconceptions and promote conceptual change among students, led to a paradox situation. Although in Cyprus the relative share of educational costs in GDP has been increasing over the years from 3.9% of the GDP in 1990 to 7.1% in 2007 and is relative high compared with the EU-27 average of 5.21% (Cyprus Statistical Services, 2011), the average performance of Cypriot students is one of the lowest compared to the others as stated previously in paragraph 1.1. In order to address this situation immediate and effective measures must be taken, and the present study aims to be a small step towards addressing this paradox situation.

1.3 CONTEXT OF THE STUDY

Cyprus, with a population of about one million people, is an island in a very strategic position in the East Mediterranean Sea and it was once the centre for the followers of Aphrodite, the Greek Goddess. Unique to Cyprus may be the influence of the ancient Greek civilization, where the knowledge of theory was considered superior to the knowledge of practical skills (Persianis, 1996).

The Cyprus Educational System comprises the following categories:

- Pre-primary Education 3 to 6 years
- Primary Education 6 to 12 years

- Lower Secondary Education (Gymnasium) 12 to 15 years
- Upper Secondary Education (Eniaio Lykeio or Secondary Technical and Vocational School) 15 to 18 years
- Higher and University Education 18+

In our research we will focus on upper secondary education, and specifically the Secondary Technical and Vocational Education (STVE). According to Bradshaw (1993) one of the primary concerns of the Cyprus government since independence from Britain in 1960, was the establishment and organization of technical education, because it was regarded as a contributing factor in the economic progress of the island. During the first 30 years, 11 technical schools were established. By entering a STVE school, students can choose either the vocational or technical section according to their interests. The technical section offers a curriculum with emphasis on mathematics, physical sciences, and a technology of specialization, and the vocational section emphasises on acquiring skills with much of the time devoted in workshop practice.

The Educational System in Cyprus is regarded as highly centralised. It is administered by the Ministry of Education and Culture (MOEC) which controls the curriculum, the textbooks and the other resources needed to deliver it. Local school boards are funded by the Ministry but their responsibilities are limited to matters of building maintenance, and supplies. Schools are directly controlled by the Ministry via the inspectorate and the school head-teachers, the latter having less devolved responsibility than in many other educational systems. Private schools are owned and administered by individuals or committees, but are liable to supervision and inspection by the Ministry of Education (Michaelidou, n.d.).

Pashiardes (2004) characterized the Cyprus Educational System as centralized, conservative and under the influence of governmental and teachers' organisations. The centralisation characterises also the way the teaching staff is appointed. In the public educational institutions the teaching staff is appointed, promoted and subject to disciplinary proceedings by the Education Service Committee. The said committee promotes also the inspectors and the senior officers of education.

This centralised system of educational administration had until now, an impact in curriculum development and improvement in Cyprus. Kyriakides (1999) enumerated the reasons why in the text below:

1. The design of the curriculum from 1981 and thereafter was almost completely controlled by the government inspectors and did not establish any mechanism for consulting teachers. Inspectors also controlled curriculum implementation through teacher evaluation. Promotion was granted only to teachers who demonstrated an ability to implement the official curriculum policy to the inspectors.
2. Centralisation practically prohibits differentiation among the schools, and as a consequence School Based Curriculum Development (SBCD) is negligible in Cyprus. Cypriot teachers struggle with their problems and anxieties privately, and rarely discuss them with their colleagues, or report them to their seniors. There is very rarely interaction concerned with professional issues among the staff of schools.
3. Systematic information about the conditions of schooling, educational processes, and educational outcomes for all grades and subjects appears to be lacking. In addition, teacher's evaluation system and National Curriculum, are a remnant from colonialism and do not meet the specific conditions of Cyprus.

The Cyprus Government, in an effort for the restructure and modernization of the Cyprus Education System, has launched in 2005 the Educational Reform and appointed the members of the Scientific Committee for the development of the new National Curriculum. In order to avoid repeating previous mistakes, the members of this committee and also the subcommittees for the development of the new National Curriculum for each lesson, are renowned academics and teachers and none of them is an inspector. The tasks that were assigned to the appointed teachers include the design and implementation of curriculum activities that will promote conceptual change to the students. These activities will be later integrated into the new National Physics Curriculum.

1.4 RATIONALE FOR THE STUDY

The educational system of Cyprus is undergoing a major reform at this time period. One of the main objectives of this reform is the revision of the National Curriculum and the accompanying textbooks for every teaching subject. Special emphasis is given to the curriculum and textbooks of Mathematics, Physical Sciences and Technology because of the priorities of the European Union and the demands of the modern society (Educational Reform Committee, 2004).

One important task that has been assigned to the subcommittee for the development of the new Cypriot National Physics Curriculum (of which I happen to be a member) is to design curriculum, instruction and the accompanying textbooks in such a way that students' erroneous prior conceptions for natural phenomena will be replaced with the corresponding scientific acceptable ideas and perceptions.

The researchers agree that the first step in the planning of instructive interventions and learning activities to this direction is the detection and the assessment of students' prior conceptions that are in conflict with the accepted meanings and hinder them from achieving the desired learning goals (Shipstone, 1988; Davis, 2001; Koltsakis & Pierratos, 2006).

Since no exclusive category of terms has been implied to describe students' existing knowledge that contradicts with the scientifically accepted meanings, in this study the term preconceptions will be used to describe prior knowledge that differs from that which is to be learned but can easily be revised through instruction (Chi & Roscoe, 2002), and misconceptions to describe "incorrect features of students' knowledge that are repeatable and explicit" (Leinhardt, Zaslavsky, & Stein, 1990, p.30). In our study we have focused on misconceptions as the subjects of our research were 16 year old students, so we believe that these students after completing 10 years of instruction mostly hold erroneous perceptions that have persisted despite instruction.

The misconceptions that persist despite formal teaching are divided into two categories. The first category includes the misconceptions that were found in almost all the research studies, in countries with different educational systems and social standings. These misconceptions do not appear to be influenced by the students' sex, age or religious convictions. The second category accumulates all those misconceptions for which it has

been proved that emanate from the educational system, or the sex, educative level, social status and religious convictions of the students (Driver and Bell, 1986; Driver, 1989; Mutimucuo, 1998; Osborne & Freyberg, 1985; Tytler, 2002; White & Gunstone, 1992; Widodo *et al.*, 2002).

So as an effort to contribute to the Cypriot National Physics Curriculum reformation process, the researcher:

1. Conducted a research among Cypriot students in order to assess and evaluate their perceptions about simple electric circuits and uncover the misconceptions students hold about those circuits.
2. Devised and implemented a four-week instructional unit underpinned by a conceptual change model synthesized by J. Stepan (Stepan, 1994) after meticulous examination of the research results and an extensive review of the related literature.
3. Measured the effect that learning activities based in Stepan's Conceptual Change Model (CCM) (Stepan, 1994) had, at helping students overcome the aforementioned misconceptions and replace them with scientifically accepted ideas which was incorporated in a four-week instructional unit.

1.5 OBJECTIVES OF THE STUDY

The objectives of this study were: a) to investigate and categorise the Technical and Vocational school students' misconceptions about simple electric circuits and b) to measure the effectiveness that conceptual change model-based instructional activities have at changing these misconceptions towards scientifically accepted ideas and promoting conceptual change among students. The most effective learning activities will be proposed to be incorporated into the new National Physics Curriculum of Cyprus' schools.

1.6 RESEARCH QUESTIONS

The research questions that emanate from the objectives of the research that we have outlined above are:

1. **What are the misconceptions of Cypriot Secondary Technical and Vocational Education (STVE) students about simple electric circuits?**
2. **Do these misconceptions change towards scientifically accepted ideas after the implementation of a four-week instructional unit taught using Conceptual Change Model Based Instruction (CCMBI)?**
3. **What is the effect of Conceptual Change Model Based instructional activities on students' misconceptions about simple electric circuits?**

1.7 SIGNIFICANCE OF THE STUDY

This study is of significance to the domain of students' misconceptions about simple electric circuits, as it extends the knowledge base that currently exists in that field.

Additionally, this research is significant to education policy makers and curriculum planners because it outlines the measures needed to be taken for a successful educational reform. In fact Cyprus Educational Service Commission understanding the significance of this study, has detached the researcher in the Office of Curriculum Development in order to join a three member team that will write the new textbooks and the accompanying instructional support materials for the new Cypriot National Physics Curriculum.

1.8 OPERATIONAL DEFINITION OF TERMS

The following operational definitions are applicable to the study:

Preconceptions: Prior knowledge that differs from that which is to be learned, but can easily be revised through instruction (Chi & Roscoe, 2002).

Misconceptions: Students' conceptions that persist despite instruction, and are incompatible with the scientifically acceptable knowledge.

Simple electric circuits: Simple electric circuits are circuits that consist of three basic components: power sources (e.g. batteries), electrical loads (e.g. bulbs or resistors), and conducting wires. “Usually the most simple electric circuit is seen as a system where a power source and a resistor are connected by two conducting wires” (Härtel, n.d, p.14).

Conceptual Change: The outcome of a complex cognitive as well as social process whereby rational beings may alter or abandon existing conceptions for ones that are widely supported by empirical evidence (Posner *et al.*, 1982).

Conceptual Change Model Based Instruction: A model of instruction where students learn by actively identifying and challenging their existing conceptions and skills (Stepans *et al.*, 1999).

Conceptual Change Model Based instructional activities: Activities that promote criteria-driven reasoning (comparing against scientifically established criteria) with evidence, encourage collaborative learning and promote conceptual change among students. In these activities, students are asked explicitly to predict what would happen in a situation, discuss predictions and reasoning with their classmates, and through a set of targeted challenges and opportunities, students are lead to a new level of understanding that is reinforced through application and extension of ideas and skills. Ultimately, students are invited to come up with their own ideas and questions to test (Stepans *et al.*, 1999).

1.9 SUMMARY OF THE CHAPTER

This is an introductory chapter which describes the background and statement of the problem, context, rationale, objectives of the study, the research questions and finally the significance of the study and definition of terms. It starts by focusing on students' misconceptions which although they have proven by a series of observations and empirical research to stand as an obstacle to what students are expected to learn, they are usually either been ignored or inadequately considered in the development of science curricula. The researcher in order to help students overcome this obstacle followed the guidelines provided by renowned researchers in this field, determined the objectives of the study, and subsequently formulated the research questions.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In the previous chapter the problem statement, the context and the rationale of the study were discussed and the research questions that guided the study were identified. In this chapter, the findings of an in-depth literature review of students' misconceptions about simple electric circuits, theory of conceptual change and conceptual change-based instructional models are presented and the theoretical framework of this study is discussed. Finally a summary of the chapter is given.

2.2 MENTAL MODELS AND MISCONCEPTIONS ABOUT SIMPLE ELECTRIC CIRCUITS

As we have outlined previously in paragraphs 1.2 and 1.4, students come to school with preconceptions, pre-formed ideas and conceptions that pre-exist formal teaching. These preconceptions form the mental framework, the scaffolding, on which students build all subsequent knowledge. New information and ideas which students receive are reinterpreted and rearranged to fit within this scaffolding. However, frequently their intuitive understanding of the world around them does not agree with the scientific explanation. So it's important in planning instruction to know how these pre-formed ideas and conceptions differ from the scientific explanation, and why children construct these ideas. The reason for exploring students' ideas parallels the theory that students' ideas constrained and channelled learning, so knowledge of students' ideas should inform teaching (Talsma, 2008). As it's virtually impossible for a single researcher to explore student's pre-formed ideas in all the fields of Physics, in our study we will focus in the field of electricity and specifically in simple electric circuits.

Students' misconceptions about electricity have been the topic of study for researchers in the last 30 years. These studies have focused in simple electric circuits, flowing current in the electric circuits and especially the brightness of bulbs in simple circuits (Shipstone, 1984; Osborne & Freyberg, 1985; Psillos, Koumaras & Valassiades, 1987; Heller & Finley, 1992; Driver, Squires, Rushworth & Robinson, 1994; Chambers & Andre, 1997; Engelhardt & Beichner, 2004; Küçüközer & Kocakulah, 2007).

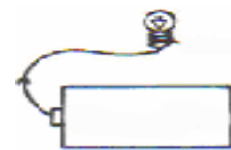
These misconceptions are usually formed before students enter formal education and follow them since (Osborne & Freyberg, 1985). But misconceptions can also be created during formal education and can be firmly held despite science teaching (White & Gunstone, 1992; Sencar & Eryilmaz, 2004).

The reason that a pleiad of misconceptions exist despite the fact that electricity is a distinct concept which students frequently encounter in everyday life is perhaps owed to the fact that electric current is not something visible and the students is unable to comprehend what happens when a current of electrons flows through a circuit (Carlton, 1999). In a study Garnett and Treagust (1992) have determined that students understand current as a flow of positive charges (mainly protons) through wires, a misconception that could be owed to the fact that students confuse the conventional with the real flow of current in an electric circuit.

After a detailed review of the related literature (Cohen, Eylon & Ganiel, 1983; Osborne & Freyberg, 1985; Psillos, Koumaras & Tiberghien, 1988; Shipstone, Jung & Dupin, 1988; Koumaras, Psillos, Valassiades & Evangelinos, 1990; Driver *et al.*, 1994; Borges & Gilbert, 1999; Koltsakis & Pierratos, 2006) we have summarized the most common students' misconceptions that have been investigated and recorded in the thematic region of simple electric circuits. Below are these misconceptions presented; most of them in the form of mental models.

1. **The unipolar or sink model:** In this model students believe that in order to complete a simple circuit with a battery and a light bulb we only need a lead that connects the battery with the light bulb (Figure 2.1). The electric current flows from a pole of battery to the light bulb and does not return. If a second lead exists in the circuit then this is extra or unnecessary (Osborne & Freyberg, 1985; Koumaras *et al.*, 1990; Driver *et al.*, 1994; Borges & Gilbert, 1999; Koltsakis & Pierratos, 2006).

Figure 2.1 *The unipolar model*



2. **The clashing currents model:** In this model (Figure 2.2), two leads are used to connect the battery with the light bulb. In the resulting circuit two electric currents with opposite directions flow inside the wires, “collide” inside the light bulb and cause the light bulb to illuminate (Osborne & Freyberg, 1985; Driver *et al.*, 1994; Borges & Gilbert, 1999; Koltsakis & Pierratos, 2006).

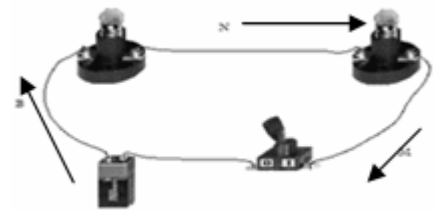
Figure 2.2 *The clashing currents model*



3. **The weakening current model:** In this model students believe that there is an electric current that flows around the circuit, but this current weakens progressively. The explanation that is given for this decrepitude is that part of the electric current “is consumed” in the interior of the light bulb (Osborne & Freyberg, 1985; Koumaras *et al.*, 1990; Driver *et al.*, 1994; Borges & Gilbert, 1999; Koltsakis & Pierratos, 2006).

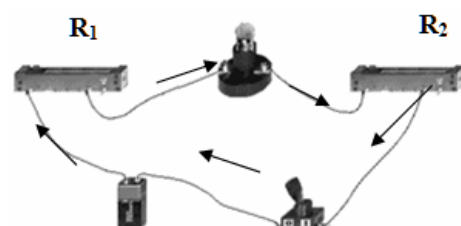
4. **The shared current model:** In this model (Figure 2.3), the students perceive that the electric current is shared equally among the light bulbs that illuminate the same. However and in this occasion the electric current is not maintained, because the light bulbs “consume” a part of it, so that less current returns in the battery (Osborne & Freyberg, 1985; Koumaras *et al.*, 1990; Driver *et al.*, 1994; Koltsakis & Pierratos, 2006).

Figure 2.3 *The shared current model*



5. **The sequence model:** In this model the students believe that messages about changes taking place in a circuit are carried forward in the direction of the current but not backwards. So when we present the circuit illustrated in Figure 2.4 to the students and ask them to predict what will happen to

Figure 2.4 *Circuit used to test for application of the sequence model*



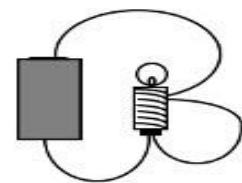
R₁ & R₂: Resistors

the brightness of the lamp if either resistor R_1 or resistor R_2 is changed, many understand that increasing or decreasing R_1 will cause the brightness of the lamp to decrease or increase, respectively, but argue that changing the value of R_2 will have no effect whatever upon the brightness since it comes after the lamp (Shipstone, 1984; Engelhardt & Beichner, 2004).

6. **The local reasoning model:** In this model students are focusing their attention entirely upon what is happening at one point in a circuit and completely ignoring whatever may be happening elsewhere (Cohen, Eylon & Ganiel, 1983; Heller & Finley, 1992).

7. **The short circuit model:** Students believe that in a circuit, wire connections without devices attached to the wire can be ignored. For example in Figure 2.5 students believe that the light bulb will illuminate despite the fact that a short circuit exists (Shipstone, Jung & Dupin, 1988; Engelhardt & Beichner, 2004).

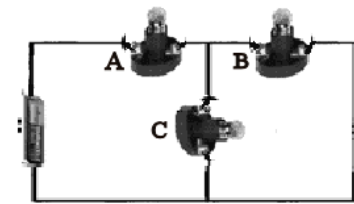
Figure 2.5 *The short circuit model*



8. **The battery as current source:** Students consider that the battery is a constant current source rather than a constant potential difference source (Cohen, Eylon & Ganiel, 1983; Psillos, Koumaras & Tiberghien, 1988; Heller & Finley, 1992; Borges & Gilbert, 1999).
9. **Battery and resistive "Superposition principle":** In this misconception students believe that if we connect X resistors or Y batteries with each other, then the equivalent resistance and the total potential difference will be $X \times R$ and $Y \times E$ respectively, regardless of the resistors or batteries arrangement. The same misconception occurs when students are calculating the power or energy delivered to a circuit. For example students in order to calculate the power delivered to a resistor don't use the relation between the quantities power, potential difference and resistance ($P = V^2/R$), but a quantitative casual relation between the number of bulbs or resistors and the number of batteries that are included in a circuit, without considering the resistors or batteries arrangement (Koumaras *et al.*, 1990; Engelhardt & Beichner, 2004).

10. **Topology:** In this misconception students consider that all resistors lined up in series are in series whether there is a junction or not. So in Figure 2.6 students think that light bulbs A and B are connected in series, disregarding the existence of a junction. They also think resistors lined up geometrically in parallel are in parallel even if a battery is contained within a branch (Engelhardt & Beichner, 2004).

Figure 2.6 Topology



11. **Term confusion:** Students confuse the terms that occur in simple electric circuits. For example potential difference or resistance is viewed as properties of current. Therefore if there isn't any flow of current inside a resistor, then this resistor has zero resistance. Students also confuse electric charge with electric energy (Koumaras *et al.*, 1990; Engelhardt & Beichner, 2004).
12. **Rule application error:** In this misconception students misapply a rule governing circuits. For example, in order to find the equivalent resistance, they use the equation for resistors in series when the circuit shows resistors in parallel (Koumaras *et al.*, 1990; Engelhardt & Beichner, 2004).

Taking all the above into account, it seems that a lot of misconceptions about simple electric circuits exist and that even after several years of science instruction, students maintain incorrect ideas about electrical phenomena. In an effort to help students restructure their existing conceptions towards scientifically acceptable ones, a group of science education researchers and science philosophers at Cornell University developed a theory called "Theory of Conceptual Change" (Posner *et al.*, 1982).

2.3 THEORY OF CONCEPTUAL CHANGE

The "Theory of Conceptual Change" was first developed in the early 1980's by Posner, Strike, Hewson, & Gertzog, at Cornell University. This theory is based on Piaget's (1929, 1930) ideas of *assimilation* and *accommodation* as well as Thomas Kuhn's description of scientific revolution (Kuhn, 1970), and Imre Lakatos's (1970) notion of theoretical hard core ideas to formulate their model of learning.

According to the Conceptual Change Model (CCM) *assimilation* refers to “the use of existing concepts to deal with new phenomena” and *accommodation* involves “replacing or reorganizing the learner’s central conceptions” (Posner *et al.*, 1982, p.212). Of the two patterns of change, accommodation signifies a radical change involving the abandonment of the existing conception and the acceptance of a new conception. Paradigms and theoretical hard core ideas are characterized as the “background of central commitments which organize research” (Posner *et al.*, 1982, p.212).

The central commitment of the CCM is that learning is a rational activity that can be defined as coming to comprehend and accept ideas because they are seen as intelligible and rational (Suping, 2003).

Although Posner *et al.* (1982) provided no formal definition of the term conceptual change, they have specified that the conditions needed for students to undergo conceptual change are:

- to become dissatisfied with the existing conception
- to find the new conception intelligible, plausible, and fruitful in a variety of new situations.

Posner *et al.* (1982) have also used the idea of conceptual ecology from Toulmin (1972) to consider the context in which conceptual change occurs. Students’ conceptual ecology is crucial to the CCM because “Whenever the learner encounters a new phenomenon, he must rely on his current concepts to organize his investigation. Without such concepts it is impossible for the learner to ask a question about the phenomenon, to know what would count as an answer to the question, or to distinguish relevant from irrelevant features of the phenomenon” (pp.212-213).

2.4 DIFFERENT MODELS OF CONCEPTUAL CHANGE

Since its inception, the CCM has been widely accepted and considered as influential, but has also been the subject of criticisms. According to Tao and Gunstone (1999) these criticisms are mainly levelled at its rational nature that it neglects noncognitive factors (e.g., motivational and classroom contextual factors) which may also affect conceptual change. Strike and Posner (1992), in a further explication of the CCM, also argued that a

wide range of factors needs to be taken into account in conceptual change.

In the following years, other models of conceptual change have been proposed (Champagne, Gunstone, & Klopfer, 1985; Carey, 1991; Chin & Brewer, 1993; Stepan, 1996). These models are presented below.

Champagne, Gunstone, and Klopfer (1985) proposed the Ideational Confrontation Strategy. This strategy applies the principle of verbal interaction to foster conceptual change. The strategy requires that, in preparation for instructional events (demonstration, laboratory exercise, problem solution, reading text), the physical situation which provides the instruction's context is described for the students. After the physical situation is described, each student engages in the analysis of the physical situation and states the concepts, propositions and variables that are relevant to the situation. After each student has analysed the situation, a class discussion begins and individual students present their analyses of the situation. An individual student's analysis is elaborated and modified by other students whose analyses are essentially in agreement. Inevitably, controversies arise, usually identified because of differences in predictions about what will happen. Typically, two students with alternative perspectives begin to attempt to convince others of the validity of their ideas. As a student or group of students defends a position, the concepts become better defined, and underlying assumptions and propositions are stated explicitly. The net result is that each student is explicitly aware of his or her analysis of the situation of interest.

In Carey's (1991) model, change between concepts can be achieved through three processes: *replacement*, *differentiation*, and *coalescence*. In replacement, an initial concept is replaced by another alternative concept, because the two concepts are so fundamentally different that the acceptance of one concept overwrites the existence of the other. Differentiation is another process in which the initial concept splits into two or more new concepts that take the place of the original. These new concepts may be incommensurate to the initial concept or to each other. Coalescence is the opposite process of differentiation; Coalescence involves two or more original concepts coalescing into a single concept that replaces the originals.

Chin and Brewer (1993) presented an instructional procedure that uses anomalous data to facilitate conceptual change. In this instructional procedure the students participate in a sequence of learning events such as the following:

1. Consider a physical scenario whose outcome is not known.
2. Predict the outcome.
3. Construct competing theoretical explanations to support the predictions.
4. Observe the outcome (anomalous data).
5. Modify competing theoretical explanations, if necessary.
6. Evaluate competing explanations.
7. Reiterate the preceding steps with different data.

The learning sequence begins with students considering a physical scenario whose outcome is not yet known (e.g., the teacher could present an electrical circuit where a short circuit occurs and ask what will happen when the switch is turned on). Then students predict what the outcome will be and justify their predictions with theoretical explanations. In a small-group or class discussion, different students will probably advance different explanations; if the resulting set of explanations does not include the accepted explanation, it's possible for the teacher to suggest it as another alternative. Students observe the outcome of the experimental situation, and then they evaluate the competing theories and the anomalous data in light of the observations that they have just made. They could also consider other relevant data as they make their evaluations. At the same time, the students refine their understanding of the competing theories in terms of how they must be adjusted to fit the new data.

Stepans (1994) formalized a six-stage Conceptual Change Model that provides a framework to improve learning. Students first write down their beliefs by making a prediction or formulating the outcome related to a concept. Students then share their views and ideas with peers. Zeidler (1997) considers this sharing of ideas as a scaffolding technique that helps students articulate their beliefs about the topic at hand and then resolve conflicts.

The six stages are:

1. Students become aware of their own preconceptions about a concept by thinking about it and making predictions (*committing to an outcome*) before any activity begins.
2. Students *expose their beliefs* by sharing them, initially in small groups and then with the entire class.
3. Students *confront their beliefs* by testing and discussing them in small groups.
4. Students work toward *resolving conflicts* (if any) between their ideas (based on the revealed preconceptions and class discussion) and their observations, thereby *accommodating the new concept*.
5. Students *extend* the concept by trying to *make connections* between the concept learned in the classroom and other situations, including their daily lives.
6. Students are encouraged to *go beyond*, pursuing additional questions and problems of their choice related to the concept.

By comparing these models we observe that despite their differences these models share four common characteristics. First, all models acknowledge that student's prior knowledge impacts the students ability to formally learn a new concept. So students' prior knowledge about a concept must become explicit in an early stage. Secondly, all models assume that students resist change to their preconceived knowledge structures. That means a strategy that encourages students to modify their preconceived knowledge structures towards scientifically acceptable ones must be devised. Thirdly, the process of conceptual change is time consuming and involves multiple steps so careful planning must take place. Finally, all these models involve that students must participate actively in the classroom.

2.5 TEACHING FOR CONCEPTUAL CHANGE

According to Davis (2001) simply presenting a new concept or telling the students that their views are inaccurate will not result in conceptual change, because students have relied on their preconceptions to understand and function in their world.

Research (Arons 1990, McDermott, 1991; Vosniadou & Brewer, 1992) showed that students who are exposed to scientific concepts would hardly give up their prior mental models completely, because these models are grounded in a long personal experience. They will try to change their previous conception when they are confronted with the new idea but still they might integrate both to build a new framework.

In science education literature various instructional strategies have been proposed in order to promote conceptual understanding and instigate conceptual change among students. These include "Cognitive Conflict" (Thorley & Treagust, 1989; Duit, 1999), "Concept Substitution" (Grayson, 1994), and "Physics-by-Inquiry Tutorials" (Shaffer & McDermott, 1992; McDermott & Shaffer, 1998).

One instructional strategy to engender conceptual change is *cognitive conflict*, where the teacher explicitly provides evidence or positions in conflict with students' mental models in order to create a state of cognitive conflict or disequilibrium (Duit, 1999). Cognitive conflict strategies are aligned with Posner *et al.*'s (1982) theory of conceptual change in that their common goal is to create the four conditions necessary for conceptual change. That is, learners must become dissatisfied with their current conceptions and accept an alternative notion as intelligible, plausible, and fruitful (Davis, 2001).

Grayson (1994) developed another instructional strategy to engender conceptual change called *concept substitution*. This instructional strategy is appropriate when students express an intuitive idea that is correct when explaining observed phenomena but rather limited in terms of lack of appropriate knowledge about the specific science term suitable for the observed phenomena. In this strategy students' correct idea is being reinforced, but with substituting the correct science term instead of the "naive" term students use to explain the science phenomena (Ferrer, 2008).

Grayson (1994, 2004) argues that instead of challenging a students' view of current consumption as mentioned in section 2.2 she provides the following reinterpretation: The view that something is consumed is not wrong at all—if seen in terms of energy. Energy actually is flowing from the battery to the bulb while current is flowing and is "consumed", i.e., transformed into heat and light.

This technique is much more agreeable for students, because it confirms their ideas to some extent. Students accept concept substitution well, because unlike cognitive conflict

it doesn't require radical restructuring of ideas on their part, but only a modification of their existing ideas. The limitation of this strategy is that it cannot always be implemented (e.g. impetus ideas, Newton's third law etc.) (Planinić, Krsnik, Pećina & Sušac, 2005).

Shaffer and McDermott (1992) proposed an instructional strategy based on previous research (McDermott & Shaffer, 1992) that uses a set of laboratory-based instructional modules, collectively entitled *Physics by Inquiry* (McDermott, 1996). Their approach is that the direct experience of using laboratory equipment encourages students to make the necessary mental commitment for conceptual change, by guiding them through the process of constructing a conceptual model for a particular concept from direct “hands-on” experience with this equipment.

For example, in one of these modules, *Electric Circuits*, students begin the process of constructing a conceptual model for electric current by trying to light a bulb with a battery and a single wire. From this, students come up with a list of necessary conditions for lighting a bulb. Here the concept of a complete circuit is introduced, and by examining the internal structure of a light bulb, students begin to understand the path of current. Circuit diagrams are then introduced and examined. Next, the concept of a flow is introduced by connecting nichrome wire to the terminals of a battery. Their observation that the wire becomes warm provides a basis for the following assumptions: a) a flow exists in a complete circuit and b) bulb brightness indicates the amount of flow. The resulting “flow” is called the electric current (Shaffer & McDermott, 1992).

2.6 CONCEPTUAL CHANGE INSTRUCTIONAL MODEL

Cognitive conflict has been used as the basis for the developing of the majority of the models and strategies that have been described earlier (see sections 2.4 & 2.5). Davis (2001) mentions that although these models suggest different methods and techniques, they share a structure similar to the three-step conceptual change teaching strategy proposed by Nussbaum and Novick (1982):

1. a) Reveal student preconceptions by creating an “exposing event”
b) Encourage students to discuss and evaluate their preconceptions
2. Create a “discrepant event” to induce conceptual conflict with those preconceptions

3. Encourage and guide conceptual restructuring

2.6.1 REVEAL STUDENT PRECONCEPTIONS

The first and most significant step before a conceptual change can occur is that “the naive concepts that students possess have to be made explicit” (Wichmann, Gottdenker, Jonassen & Milrad, 2003, p.382).

To elicit students’ conceptions, instruction begins with an “exposing event”. The term *exposing event* refers to “a phenomenon carefully selected for its ability to evoke students’ preconceptions in order to understand it”. (Nussbaum & Novick, 1982, p.187).

Chin and Brewer (1993) classified these exposing events in two categories:

- a category in which the outcome of the event is unknown and the teacher calls students to predict the outcome and explain the basis for their prediction and
- a category in which the outcome of the event is known. In this occasion, students make no predictions but nevertheless, they must provide an explanation of the event.

Students can use a variety of ways to expose their ideas. Morrison and Lederman (2002), mention that the techniques that may be used to elicit students’ ideas include “concept maps, interviews, discussions, small group work, specific activities, journal writing, and pencil and paper quizzes” (p.850). Regardless of the method, the goal of this step is to help students recognize and begin to clarify their own ideas and understandings. Once students’ conceptions are made explicit, teachers can use them as the basis for further instruction (Davis, 2001).

2.6.2 DISCUSS AND EVALUATE PRECONCEPTIONS

In this step students use group or/and whole-class discussions to clarify and revise their original conceptions. Davis (2001) suggests that if this is the teacher’s first conceptual change learning activity, “it is wise to begin with the latter; such discussions allow the teacher to model the evaluation process before students evaluate each other’s ideas in smaller groups” (para. 26).

According to Morrison and Lederman (2002) it is important that the teacher must ask the right type of questions to see what students understand about a concept. For example a question like “How many of you have talked about atomic structure in other science classes?” (p.853) may be informative for the teacher for planning purposes but does not comprise any in-depth diagnosis of students’ understanding. But if the teacher asks various students the question “Can anyone describe the structure of an atom?” (p.853) then he will be able to diagnose their prior knowledge.

After all conceptions are presented the teacher asks students with differing conceptions to work in pairs or groups and evaluate each other's ideas. Each group picks a conception and presents it to the whole class accompanied with a rationale for the selection. The teacher discusses these conceptions and evaluates each for its intelligibility, plausibility and fruitfulness. Students at this point can also express their opinion on the conception which they think that explains better the exposing event.

2.6.3 CREATE CONCEPTUAL CONFLICT

In this step the teacher creates a “discrepant event” to induce conceptual conflict. Davis (2001) defines *discrepant event* as “a phenomenon or situation that cannot be explained by the students' current conceptions but can be explained by the concept that is the topic of instruction” (para. 31). At this point, if the resulting set of students’ conceptions does not include the “correct” conception, then the teacher may suggest it as another alternative. It is also possible for the teacher to create a discrepant event by presenting anomalous data evidence that contradict the students' current conceptions (Chinn & Brewer, 1993).

Davis (2001) concludes that “as students become aware of their own conceptions through presentation to others and by evaluation of those of their peers, students become dissatisfied with their own ideas; conceptual conflict begins to build. By recognizing the inadequacy of their conceptions, students become more open to changing them.” (para. 30).

2.6.4 ENCOURAGE AND GUIDE CONCEPTUAL RESTRUCTURING

At this point the teacher presents the scientific explication. He must prove it is intelligible, plausible and fruitful. Then, the students are encouraged to reconstruct their

ideas and reconcile differences between their conceptions and the target theory. Conceptual change will occur only if the status of scientific conceptions is higher than the status of students' pre-instructional conceptions (Epitropakis, 2005). Students should be given a fair amount of time to complete this step, because the process from students' initial models to scientific models is gradual, through synthetic models and time consuming (Vosniadou, 2002).

2.6.5 A COMBINATION OF REAL EXPERIMENTATION AND SIMULATION INSTRUCTIONAL STRATEGY

Real experimentation has long played a vital role in science education (Hofstein & Lunetta, 1982, 2004). Science educators have suggested that experiments are an important medium for introducing students to central conceptual and procedural knowledge and skills in science, especially when grounded on the principles of *inquiry* (Bybee, 2000; Hofstein & Lunetta, 2004; de Jong, 2006).

In this context, students use the methods and procedures of science to investigate phenomena, solve problems and pursue interests in order to:

- develop an understanding of the scientific concepts, models and theories and
- acquire an understanding of the nature and methods of scientific inquiry, including an awareness of the complex interactions between science, technology, society and environment (Hofstein & Lunetta, 2004).

The challenge for real experimentation or any other form of experimentation is to help learners take control of their own learning in a search for understanding. In this process, it is vital to provide opportunities that encourage learners to ask questions, suggest hypotheses and design investigations – ‘minds-on as well as hands-on (Gunstone & Champagne, 1990; Gunstone, 1991). There is also a need to provide students with frequent opportunities for feedback, reflection and modification of their ideas (Barron *et al.*, 1998).

Researchers have also reported the success that computer simulations had at overcoming students' preconceptions when used in a conceptual change instructional strategy (Gorsky & Finegold, 1992; Carlsen & Andre, 1992; Koltsakis & Pierratos, 2006; Chang & Sung, 2008; Trundle & Bell, 2010). The reason for this success is owed to the fact that

computer simulations are offering many attributes that are useful for promoting cognitive conflict, a crucial factor for promoting conceptual change according to the CCM. Simulations, by providing simplified versions of the natural world, allow students to focus their attention more directly on the targeted phenomena (de Jong & Van Joolingen, 1998). Simulations may allow students to visualize objects and processes that are normally beyond perception. Moreover a great number of simulations allow students to manipulate variables that are beyond the users' control in the natural world (e.g. gravitational acceleration). According to Winn et al. (2006) computer simulations have the potential to promote conceptual change more effectively than direct experience. Computer simulations can also provide students with highly focused objects for reflection and discussion. Working in small groups, students can discuss and argue about their ideas and negotiate meaning. When confronted with discrepant results, they have to reflect on their ideas, discuss and try new approaches, and rerun the simulation (Tao & Gunstone, 1999).

The Physics Education Technology (PhET) project at the University of Colorado in an effort to promote the use of computer simulations in the physics classroom, developed a suite of physics simulations that span the curriculum of introductory physics and are freely available online. These simulations take advantage of the opportunities of computers while addressing some of the limiting concerns of these tools. Research by the PhET project indicated that the use of simulations has a great impact on students' understanding of electricity concepts (Finkelstein *et al.*, 2005).

A growing body of researchers (Zacharia & Anderson, 2003; Zacharia, 2007; Jaakkola & Nurmi, 2008; Zacharia & Olympiou, 2010) argues that the combination of real experimentation and computer simulations can be effectively used to achieve cognitive conflict and conceptual change among students.

2.7 THEORETICAL FRAMEWORK FOR THIS STUDY

As discussed previously (see section 2.4), various conceptual change strategies through which students alter their alternative conceptions towards scientific accepted ideas, exist. Among these conceptual change strategies, we have chosen to implement the Conceptual Change Model for instructional design, developed by Joseph I. Stepan.

This 6-stage Conceptual Change Model (CCM) is an activity-centred, constructivist teaching-and-learning strategy that places students in an environment that encourages them to identify and confront their own preconceptions and those of their classmates, then work toward resolution and conceptual change (Stepans, 1988, 1991, 1994). It also models collaboration and the kind of thinking and activity processes typical of scientific inquiry (Stepans *et al.*, 1999).

Stepans's conceptual change strategy is based on Posner *et al.*'s (1982) theory but also takes into account new knowledge and perspectives in cognitive science and science education that have developed since this theory was introduced about 30 years ago. Perhaps most significantly, it begins with explicitly revealing the students individual preconceptions about a concept, causing them to commit to a prediction and share explanations as a group before working with materials. As a result, they become actively engaged in challenging their existing ideas.

Stepans's CCM incorporates the research of several previous authors (Nussbaum & Novick, 1982; Posner *et al.*, 1982; Clement, 1987; Driver & Scanlon 1989; Stepans, 1988, 1991). As a result, in Stepans' CCM the teacher and the student are both learners—the teacher is no longer the answer-holder. Both students and teachers confront change in themselves through the use of the model (predicting, sharing predictions and explanations, testing, resolving the concept, building connections, and leaving the topic open for future questions) to learn about a science concept. The teacher may use many of these same steps to gain an understanding of the children's attitudes, socialization, knowledge and skills. One of the strengths of the model is that it enables teachers to more accurately judge the appropriateness of the curriculum for the learners in his/her classroom.

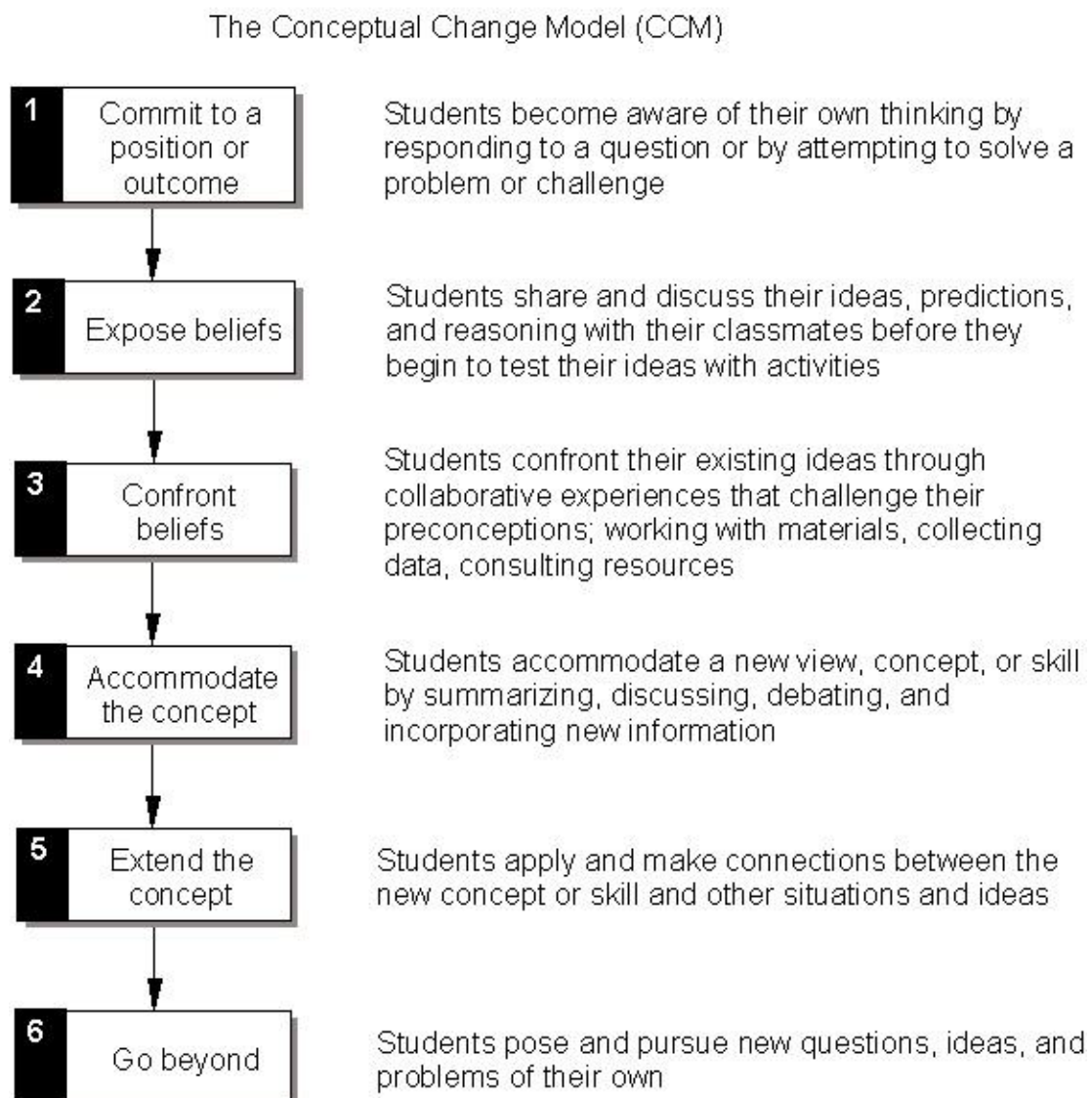
One of the most striking outcomes of Stepans's CCM that is reported by teachers is that many students who have difficulty with traditional book-based instruction do well using the CCM. Also, the teachers' observations help them to look at kids differently, to acknowledge and value the ideas learners already have, and to build upon them (Stepans *et al.*, 1999).

Furthermore, Stepans's CCM is designed to foster active student collaboration within the classroom. Students communicate with each other and the teacher, to find information and solutions to their questions and to discuss their findings and understandings. Also

through active collaboration, students learn to value and respect each other's ideas. The results of many studies indicated that collaborative learning significantly influences learning outcomes and has been associated with gains in such variables as achievement, thinking skills, interpersonal skills, and attitudes toward school, self, and others (Johnson, Skon & Johnson, 1980; Sharan, 1980; Johnson & Johnson, 1990; Johnson, Johnson, Stanne & Garibaldi, 1990; Slavin, 1990; Cohen, 1994; Qin, Johnson, & Johnson, 1995; Springer, Stanne & Donovan, 1999).

An outline of the CCM along with a brief explanation of each stage is presented in Figure 2.7 below, and a more detailed description in the following paragraphs.

Figure 2.7 Outline of the Conceptual Change Model for instructional design, developed by Joseph I. Stepan (Stepans et al., 1999, p.141)



Commit to a position or outcome phase

In this phase, the teacher asks questions to the students or presents them a problem or challenge. Students become aware of their own preconceptions about a concept by responding to the questions, or by attempting to solve the problem or challenge before any activity begins. As students formulate their answers or solutions, they become familiar with their views, and may become interested in knowing the answer to the question or the solution of the problem or challenge. During this phase the teacher does not comment on students responses.

Expose beliefs phase

Students in small groups share and discuss their ideas, predictions and reasoning with their classmates and a group member presents them to the whole class. The teacher classifies students' responses into categories and a whole-class discussion follows. This discussion gives students the opportunity to change their initial beliefs if they wish to, explaining the reasons that led them to this decision if they want. During this phase the teacher also does not comment on students responses, but may help students clarify their views using a variety of ways.

Confront beliefs phase

Students in small groups are actively engaged in learning activities, the outcome of which they are required to record and interpret after discussion among group members. The teacher in this phase provides technical assistance to students and answers clarification questions if requested. During this phase, students in most cases become dissatisfied with their existing ideas by experiencing the difference between the result they were expecting and what they actually see, thus giving the opportunity to the teacher to introduce and develop the scientific model.

Accommodate the concept phase

In this phase, students whose ideas are close to scientific acceptable ones with the aid of the teacher, explain their views to their classmates. After a procedure that includes summarizing, discussing and debating, and incorporating new information, most of the students accommodate the new concept and leave their previous concepts behind. The

teacher helps them draw conclusions and formulate principles relating to the newly acquired information.

Extend the concept phase

Students in this phase apply their newly acquired knowledge and skills in different situations. These situations may be presented by the teacher, by their fellow classmates, or by themselves.

Go beyond phase

Finally, students seek additional situations where acquired concepts or skills may be put into practice. Students can accomplish that by delving into personal experiences, questioning friends, relatives, and professionals, or conducting research to discover situations which can be dealt with in the same way

In our study, we used the CCM to target students' misconceptions in electricity. For this purpose we have developed a number of activities based on the CCM, a sample of which is presented in Appendix B. These activities address the misconceptions that were found most frequently in previous research studies, as well as in our baseline research.

The CCM-based activities were incorporated into a 4-week course on electricity, where students were introduced to the following topics: Electric current, batteries, elements and construction of a DC circuit, resistance and Ohm's Law, resistors in series and parallel, batteries in series and parallel, short circuit, electrical power and energy, and Kirchhoff's laws.

All lessons were taught by teacher-researcher. Some of the instructional activities were adopted from various sources (Koumaras, 1989; Sherwood & Shabay, 1999; Kapartzianis, Makris, & Xatzikostis, 2008; Stepan, 2008; Testa, 2008; Garganourakis, 2009a, 2009b, 2009c, 2009d) and the remaining were developed by the researcher. The activities were performed by using laboratory equipment, objects from everyday life, and ICT tools such as PowerPoint slides, and simulation software like Edison 4 and Virtual Labs Electricity.

Students were assigned to work in groups formed according to their scores in the pre-test and friendship patterns, to ensure that they will cooperate without problems for a

prolonged period of time. A more detailed discussion about the group synthesis is provided in section 3.6.2, p.54.

2.8 SUMMARY OF THE CHAPTER

The chapter started by focusing on students' mental models and misconceptions about simple electric circuits which seems to affect students' learning of physics concepts (section 2.2). Afterwards the theory of conceptual change and the different conceptual change models of instruction were discussed (sections 2.3 & 2.4). Finally the conceptual change model of instruction used in this study for the teaching and learning of physics more specifically electricity was discussed along with an attempt by the researcher to justify his choice.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

In the previous chapter a review of the related literature as well as the theoretical framework was discussed. The literature reviewed guided the researcher in selecting the research design and methods, in planning the CCM-based instructional activities.

This chapter describes the methods and procedures used in the study. These include the research design, the sample and participants of the study, the instruments used for data collection the reliability and validity of those instruments, ethical considerations, and the course design. Finally an example of application of the CCMBI strategy is presented.

3.2 RESEARCH DESIGN

This research followed the transformative mixed methods design (Creswell, 2008) where the research calls for reform of the new National Curriculum to bring about change in Cyprus. Attention is focused on one field at a time, and the focus of this study is in the field of electricity.

The researcher conducted a two part research project. The objective of the first part of the study (Part I) was to investigate and categorise the Cypriot Secondary Technical and Vocational Education (STVE) students' misconceptions about simple electric circuits and to compare these misconceptions with those reported in the literature. The results of this part of the study constituted the background for the second part of the study (Part II). Part II's objective was two-fold. a) to create and plan conceptual change-based instructional activities that aimed to address STVE students' misconceptions uncovered in Part I, thus setting the ground for conceptual change among these students and b) to measure the effect that these specifically designed instructional activities had at changing these misconceptions towards scientifically accepted ideas.

3.2.1 DEFINING MIXED METHODS RESEARCH

Mixed methods research brings together quantitative and qualitative data collection and analysis as it seeks to provide more comprehensive answers to research questions by going beyond the limitations of a single approach.

Tashakkori and Creswell (2007, p.4) describe mixed methods research as “research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or programme of inquiry”. Qualitative practices are woven together with quantitative measures in a complementary way that aims to provide the researcher with a comprehensive view of a situation (Patton, 1990). The use of multiple approaches to answer a research question does not limit the research but rather expands it and allows it to be complementary and inclusive (Johnson & Onwuegbuzie, 2004).

Hesse-Biber (2010) lists three specific reasons that made the researcher decide to use a mixed methods research:

- The first reason is triangulation. *Triangulation* refers to the use of more than one method while studying the same research question in order to “examine the same dimension of a research problem” (Jick, 1979, p.602). The researcher is looking for a convergence of the data collected by all methods in a study to enhance the credibility of the research findings. Triangulation strengthens the research as the strength of one form counteracts the weaknesses of the opposite form. Similarly, by having multiple points of check for validity, the research is less likely to be vulnerable to error due to the weaknesses of one method (Patton, 1990). Triangulation ultimately fortifies and enriches a study’s conclusions, making them more acceptable to advocate both qualitative and quantitative methods.
- The second reason that made the researcher consider incorporating a mixed methods design is *complementarity*. Complementarity allows the researcher to gain a fuller understanding of the research problem and/or to clarify a given research result. This is accomplished by utilizing both quantitative and qualitative data and not just the numerical or narrative explanation alone to understand the problem in its entirety. Both complementarity and triangulation are useful “for

cross-validation when multiple methods produce comparable data” (Yauch & Steudel, 2003, p.466).

- The third reason for using mixed methods is *development*. Mixed methods often aid in the development of a research project by creating a synergistic effect, whereby the “results from one method . . . help develop or inform the other method” (Greene *et al.*, 1989, p.259). For example, statistical data collected from a quantitative method can often shape interview questions for the qualitative portion of one’s study.

3.2.2 TRANSFORMATIVE MIXED METHODS RESEARCH DESIGN

The research design adopted for this study was a transformative mixed methods design. This design uses a transformative theoretical perspective to advocate for social change, address social injustice, or give voice to marginalized or underrepresented population (Creswell, 2008). Studies using this mixed methods design integrate quantitative and qualitative data during the analysis and interpretation phases as the researcher’s choice of method is guided by specific theoretical perspectives that are reflected in the research questions of the study. In other words, the theoretical perspective “is the driving force behind all methodological choices such as defining the problem, identifying the design and data source, and analysing, interpreting, and reporting results throughout the research process” (Creswell, Plano Clark, Gutmann, & Hanson, 2003, p.230). The transformative perspective was selected in order to provide an in-depth understanding and was utilized because STVE students are a marginalized group. The reason is because electricity, a fundamental driving force behind our modern industrialized society (Jaakola, Nurmi & Ahokas, 2005) and a topic often included in secondary curricula, is almost absent from the STVE curriculum. Electricity is at present found only at the curriculum of 2nd grade (11th grade level) advanced theoretical section, which is only selected by less than 5% of the STVE student population. This glaring omission constitutes a major drawback that needs to be addressed as soon as possible.

A definite theoretical perspective guided the research, and this research ultimately encourages a change in the status quo of education. This perspective is also the best way to capture the experiences of those who are not in the mainstream (Mertens, 2005). STVE

students, because they are rarely studied and often ignored, fit into this category (Michaelidou *et al.*, 2003).

3.2.3 PART I

In order to uncover STVE students' misconceptions about simple electric circuits a survey research design was implemented. According to Fraenkel and Wallen (1990, p.332) "*the major purpose of surveys is to describe the characteristics of a population*". Surveys are helpful to learn about individual attitudes, opinions, beliefs, practices and to evaluate the success or effectiveness of a program or to identify needs (Creswell, 2008).

Cohen et al. (2000) enumerate several characteristics and several claimed attractions of survey that influenced the researcher's choice of research design. By using a survey the researcher is able to:

- gather data on a one-shot basis and hence is economical and efficient;
- represent a wide target population;
- generate numerical data;
- provide descriptive, inferential and explanatory information;
- manipulate key factors and variables to derive frequencies;
- gather standardized information (i.e. using the same instruments and questions for all participants);
- ascertain correlations;
- present material which is uncluttered by specific contextual factors;
- capture data from multiple choice, closed questions, test scores or observation schedules;
- support or refutes hypotheses about the target population;
- make generalizations about, and observe patterns of response in, the targets of focus;

- gather data which can be processed statistically.

As in a survey research, the researcher in this part of the study was interested in the variability of the responses, how closely some responses were related to others and how responses varied within certain variables (Krathwohl, 1998).

3.2.4 PART II

In this part of the study, a combination of qualitative and quantitative research was employed. Quantitative research, consisted from a pre-experimental one-group pre-test post-test design with Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT) 1.2 translated and adopted in Greek language by the researcher as a research instrument. Qualitative research consisted of interviews and field notes taken by the researcher during the lessons and were used for triangulation.

3.2.4.1 Pre-experimental one group pre-test post-test design

Measuring the impact of an intervention poses difficult challenges for the researchers. Not only they must collect data on outcomes from the intervention, they must also measure what the outcomes would have been without the intervention. In educational research, the research designs most commonly used in impact evaluations are the experimental designs. In experimental designs, the subjects under study are randomly divided into two groups, an experimental group and a control group. The experimental group, receives the treatment while in the control group the treatment is withheld. The impact of the intervention can be measured by the difference between the means of the samples of the experimental group and the control group (Cohen *et al.*, 2000).

But often in educational research it is infeasible for the researcher to implement an experimental design. In these cases pre-experimental designs are typically used. In this study an experimental design was infeasible, because due to timetable limitations the researcher could teach only one class of students. Like experimental designs, pre-experimental designs estimate how (or if) an intervention affects the treated group. The effect's magnitude then defines how worthwhile an intervention is and, ultimately, whether its benefits justify its cost (Bell, n.d.).

The quantitative component of the research was a *pre-experimental*, one group pre-test-post-test design. In pre-experimental methods, the researcher measures a group on at least one dependent variable (O_1), and then introduces an experimental manipulation (X). Following the experimental treatment the researcher measures the group again on that variable (O_2) to determine the effects of the manipulation (Cohen *et al.*, 2000). In this study CCMBI, the independent variable, was implemented to determine the effect on students' level of understanding of simple electric circuits.

The one group pretest-post-test design can be represented as:

Figure 3.1 *One-Group Pre-Test-Post-Test Design (Cohen et al., 2000, p.213)*



Where O is a measurement recorded on an instrument (students' misconceptions) and X is an exposure of the group to an experimental variable (curriculum project).

3.2.4.2 Interviews

Qualitative data was collected by using interviews that are defined as “a conversation with a purpose” (Berg, 2001, p.66). By “interviewing” we mean conducting individual, structured or semi-structured, question-and-answer conversations with a sample of students and recording the results of our interviews to establish a database for further reflection and action (Stepans, Saigo & Ebert, 1999). Interviews are valuable for finding out about students' misconceptions either prior to or following instruction (Bell, Osborne & Tasker, 1985). Paper-and-pencil pre-tests and post-tests can't achieve this by their own, because they are not sufficiently open-ended and don't establish a friendly dialogue that permits probing for clarification, going both ways (Stepans *et al.*, 1999). By analysing the responses from the interviews and comparing them with the test data we can draw more accurate inferences about the students under study.

In our study the interview questionnaire contained both ‘fixed-alternative’ items and ‘open-ended items’ in order to take advantage of their advantages while minimizing their disadvantages.

The advantages include (Cohen *et al.*, 2000):

- greater uniformity of measurement and therefore greater reliability, making the respondents answer in a manner fitting the response category, and being more easily coded for the ‘fixed-alternative’ items and
- flexibility, allowing the interviewer to probe so that he may go into more depth if he chooses or to clear up any misunderstandings, enabling the interviewer to test the limits of the respondent’s knowledge, encouraging co-operation and help establishing rapport, and allowing the interviewer to make a truer assessment of what the respondent really believes for the ‘open-ended items’.

Disadvantages include superficiality, the possibility of irritating respondents who find none of the alternatives suitable, and the possibility of forcing responses that are inappropriate, for the ‘fixed-alternative’ items and unexpected or unanticipated answers which may suggest hitherto unthought-of relationships or hypotheses for the ‘open-ended items’ (Cohen *et al.*, 2000).

3.2.4.3 Field notes

Field notes refer to transcribed notes or the written account derived from data collected during observations and interviews. There are many styles of field notes, but all field notes generally consist of two parts: descriptive in which the observer attempts to capture a word-picture of the setting, actions and conversations; and reflective in which the observer records thoughts, ideas, questions and concerns based on the observations and interviews (Weinberg, n.d.)

Chiseri-Strater and Sunstein (1997) have developed a list of what should be included in all field notes:

- Date, time, and place of observation
- Specific facts, numbers, details of what happens at the site
- Sensory impressions: sights, sounds, textures, smells, tastes
- Personal responses to the fact of recording field notes
- Specific words, phrases, summaries of conversations, and insider language

- Questions about people or behaviours at the site for future investigation
- Page numbers to help keep observations in order

In our study the field notes were taken during and after the classes. In the field notes, the researcher highlighted what he thought was of importance, like individual and group activities, students' attitudes and behaviours, recorded any theories that he might have developed while observing a student or a group of students, and took general notes on what students were saying or doing during classes and interviews. Field notes also included the researcher's post-interview reflections, which summarized the interview, suggested some theories about the views of individual students, and noted any questions that might have been raised through the interview.

3.3 RESEARCH POPULATION AND SAMPLE

According to Cohen et al. (2000) the correct sample size depends on the purpose of the study, the nature of the population under scrutiny, and to some extent by the style of the research. Sample size might also be constrained by cost—in terms of time, money, stress, administrative support, the number of researchers, and resources. In our research the target population was the 4063 students that studied in the STVE Schools of Cyprus during the school year 2009-2010 (Ministry of Education and Culture, 2012). Only students from the A' Technical School of Limassol were tested and involved in this study, mostly for convenience purposes, since the researcher had direct access to these students as their teacher, but also because from the researcher's own experience and from the opinions of experienced teachers and assistant headmasters with whom the researcher discussed, students from the A' Technical School of Limassol represent a typical example of Cypriot STVE students.

For the first part of the research, a diagnostic test (DIRECT) was administered to students from the A' Technical School of Limassol. Two entire classes from each grade—one from technical and one from vocational section—were randomly selected, apart from one. The research sample constituted of 73 students, that is, 22 first grade (10th grade level), 28 second grade (11th grade level), and 23 third grade (12th grade level) students.

This specific sample was selected because a researcher using these type of survey typically seeks to gather large scale data from as representative sample population as

possible in order to say with a measure of statistical confidence that certain observed characteristics occur with a degree of regularity, or that certain factors cluster together or that they correlate with each other (correlation and covariance), or that they change over time and location (Cohen *et al.*, 2000). As we have mentioned earlier in section 3.2.2, electricity is almost absent from STVE curriculum, so presumably students had the same knowledge base about electricity in each grade at the time of the survey.

For the second part of the research the sample constituted of 15 second grade (11th grade level) students from a class consisting of mechanical engineering and graphic arts with specialization in interior decoration students, in the A' Technical School of Limassol. This specific sample was selected because it was the only class in school that the researcher could teach the course he designed for this study at that specific time period. These students were tested by using DIRECT before the commencement of the 4-week, 24-period course on electricity, and again after the completion of the course. A purposive sub-sample of five students was selected from the sample of 15 for interviewing at the commencement and after the completion of the course. To ensure an approximately equal representation, the interviewees were selected according to their performance in the pre-test and gender, to ensure an approximately equal representation.

3.4 INSTRUMENTS

3.4.1 DETERMINING AND INTERPRETING RESISTIVE ELECTRIC CIRCUITS CONCEPTS TEST (DIRECT)

Tests are a powerful method of data collection and have been frequently used as assessment instruments in educational research worldwide. Lambrianou (2008) defines tests as “instruments that are used in educational research and include a series of questions or activities that are focused in a certain field and are expected to be answered from students” (p.2)

Two categories of tests exist: researcher-produced tests and published tests. In our research we have chosen to use the latter, a diagnostic instrument called Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT) version 1.2, translated and adopted into Greek by the researcher. DIRECT was developed from Paula V. Engelhardt and Robert J. Beichner, both professors of North Carolina State University to

evaluate high school and university students' understanding in a variety of resistive DC circuits concepts.

This instrument has been chosen because it fulfils many of the reasons that according to Cohen et al. (2000) make published tests attractive to researchers:

- It is objective;
- It has been piloted and refined (hence will use version 1.2);
- It has been standardized across a named population so it represents a wide population;
- It's reliability and validity has been tested and published (Engelhardt & Beichner, 2004; Ateş, 2005; Ross & Venugopal, 2005; Rosenthal & Henderson, 2006);
- It is a parametric test, thus allows sophisticated statistics to be calculated;
- It saves the researcher a considerable amount of time by sparing him from the task of having to devise, pilot and refine his own test.

DIRECT is a twenty-nine item multiple-choice test with five answer choices for all questions except one and it takes about 45 minutes (one teaching period) to complete.

The instrument is structured in four units: Physical aspects of DC electric circuits, Energy, Current and Potential difference (voltage), one for each constituent part component of scientific knowledge that is related with simple electric circuits. The questions of each unit is attempted to elicit students preconceptions, for each constituent part component of scientific knowledge.

The instrument was constructed around a set of eleven instructional objectives about simple electric circuits, which involve a number of different aspects. These objectives are presented in Table 3.1

Table 3.1 Objectives for DIRECT (from P. Engelhardt & R. Beichner, 2004, p.100)

Objectives for DIRECT		Question No
Physical aspects of DC electric circuits (objectives 1-5)		
1	Identify and explain a short circuit	10, 19, 27
2	Understand the functional two-endedness of circuit elements	9, 18
3	Identify a complete circuit and understand the necessity of a complete circuit for current to flow in the steady state	
Objectives 1–3 combined		27
4	Apply the concept of resistance including that resistance is a property of the object and that in series the resistance increases as more element are added and in parallel the resistance decreases as more elements are added	5, 14, 23
5	Interpret pictures and diagrams of a variety of circuits including series, parallel, and combination of the two	4, 13, 22
Energy (objectives 6-7)		
6	Apply the concept of power to a variety of circuits	2, 12
7	Apply a conceptual understanding of conservation of energy including Kirchhoff' loop rule and the battery as a source of energy.	3, 21
Current (objectives 8-9)		
8	Understand and apply conservation of current to a variety of circuits	8, 17
9	Explain the microscopic aspects of current flow in a circuit through the use of electrostatic terms such as electric field, potential differences, and interaction of forces on charged particles.	1, 11, 20
Potential difference (Voltage) (objectives 10-11)		
10	Apply the knowledge that the amount of current is influenced by the potential difference maintained by the battery and resistance in the circuit.	7, 16, 25
11	Apply the concept of pot. diff. to a variety of circuits including the knowledge that the pot. diff. in a series circuit sums while in a parallel circuit it remain the same.	6, 15, 24, 28, 29
Current and Potential difference (objectives 8 & 11)		26

The same test was administered prior to the teaching sequence as well as after the course completion, as we have discussed earlier in section 3.3. At a first glance, using the same test as pre-test and post-test may be seen as a disadvantage (Cohen *et al.* 2000). But as it is not the only data collection instrument we will use, the affect the validity of the data is minimal. Moreover as an extra measure the order of appearance of the questions in each test as well as the order of appearance of the answers in each question was rearranged, in order to exclude the case of students' simply memorising the correct answers in each question.

3.4.1.1 Reliability and Validity of DIRECT

According to Katsillis (2001) a measuring instrument is considered valid, when it actually measures what is intended to measure. In our research our measuring instrument (DIRECT) was checked for validity according to the guidelines provided by Cohen et al. (2000).

Although the validity of the DIRECT test has been determined and published, this has been done for the English version only. To ensure the content validity of the Greek version, the instrument was sent to two experienced Physics teachers, renowned in their field, that have years of experience in teaching STVE students. These teachers were asked to check the instrument for a number of factors that according to Gay and Airasian (2003) affect the validity of a measuring instrument like DIRECT: a) unclear test directions; b) confusing and ambiguous test items; c) using vocabulary too difficult for test takers; d) overly difficult and complex sentence structures. They both suggested that question 11 needed rephrasing, because the translation was obscure and would probably confuse students. Apart from that, both thought that, in general, the test was suitable for the assessment of students' perceptions about simple electric circuits. After their suggestions were taken into account, the necessary modifications were performed and the test was given for completion to the students during a teaching period.

On the other hand *reliability* is “the degree to which a test consistently measures what is supposed to measure (Gay & Airasian, 2003). The reliability coefficient of DIRECT was determined by using the Internal-Consistency Method. Kuder – Richardson Formula 20 (KR-20) was used for this purpose, because it has been developed and used in many research studies to measure the internal consistency reliability (Kuder & Richardson, 1937; Nunnally, 1967; McMillan, 2001). The KR-20 was calculated using SPSS and the value was 0.70 which according to Engelhardt & Beichner (2004) is acceptable for group measurements, although the value is somewhat low as a result of the low discrimination and high difficulty indices.

3.4.2 INTERVIEW QUESTIONS

This study implemented a semi-structured interview technique. The interview questions that were used were drawn from a similar research done by Prof P. Koumaras (1989) in 1989.

The specific questionnaire was chosen for the following reasons:

- It contained both ‘fixed-alternative’ items and ‘open-ended items’ in order to take advantage of their advantages while minimizing their disadvantages;
- Via the interview questions is attempted the elicitation of the majority of student misconceptions that DIRECT examines;
- It’s reliability and validity has been tested and published ;
- It saved the researcher a considerable amount of time by sparing him from the task of having to devise, pilot and refine his own questionnaire.

The interviewees were evenly selected from high, middle and low performing groups, and effort has been made to balance gender representation, by selecting one of the two girls attending the class. The interviewees were asked to answer only 14 questions, following Creswell’s suggestion that “a few questions place emphasis on learning information from participants, rather than learning what the researcher seeks to know” (Creswell, 2005, p.137). According to the progress made during the interviews, additional questions were also asked in some instances. Students were interviewed between 30 and 40 minutes time period. The researcher tried its best not to lead the students and also strived to develop an interaction in a natural and comfortable atmosphere. All the interviews were recorded with the consent of students and transcribed.

3.4.2.1 Reliability and Validity of the Interview Data

Reliability and validity of interview data has always been a problem in research. Cohen et al. (2000) suggest that the most practical way of achieving greater validity is to minimize the amount of bias caused as much as possible, by avoiding several causes of bias in interviewing such as:

- biased sampling;
- poor rapport between interviewer and interviewee;
- alterations to the sequence of questions;
- inconsistent coding of responses;
- poor use and management of support materials;

- selective or interpreted recording of data/transcripts;
- leading questions i.e. where the question influences the answer perhaps illegitimately.

The researcher conducted the interviews having all these suggestions in mind and took a series of measures in order to minimize biased results. The researcher also tried to create a pleasant environment for the interviewees by ensuring them that their answers will be kept confidential, and will be used for research purposes only and will not affect their grade in the trimester.

3.5 ETHICAL CONSIDERATIONS

When conducting an educational research the first stage before the commencement of data collection is that of access to the institution or organization where the research is to be conducted and acceptance by those whose permission one needs before embarking on the task. The first stage thus involves the gaining of official permission to undertake one's research in the target community. According to Cohen et al. (2000) this will mean contacting, in person or in writing, the officials that are in top of the hierarchy in the Ministry of Education and Culture, along with the head-master or principal of the school where the research will take place. In our case an application for conducting educational research in the A' Technical School of Limassol was filed to the Center for Educational Research and Evaluation of Cyprus (K.E.E.A.) through the webpage

http://82.116.204.20/registrations/KEEA_ResearchProposals09_10/index.fwx

and was subsequently approved.

Also students conducting research as part of their studies in the Institute for Science and Technology Education are required to seek ethical clearance from the UNISA Ethical Review Committee. An application for ethical clearance has been made and approval has been granted (see APPENDIX C).

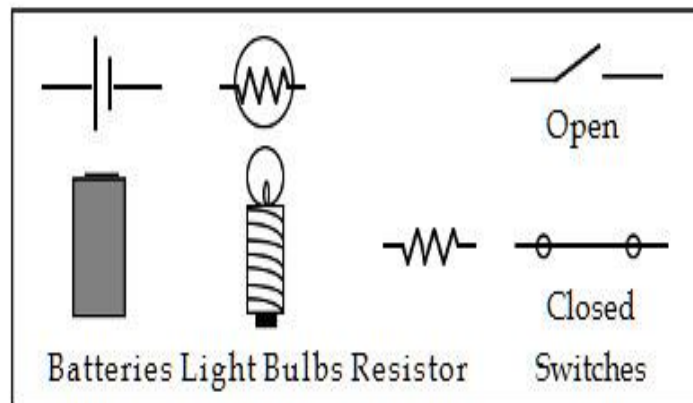
3.6 METHODOLOGY

3.6.1 PART I

The first part of the study focused on identifying students' misconceptions about simple electric circuits. The survey design used, implied that the data would be collected at one point in time. The researcher in order to minimize factors that could affect the reliability and validity of the data, chose to distribute the test to the students on April 12, 2010 the first Monday after the Orthodox Easter vacations, so that the students would be relaxed and eager to participate in a survey. The tests along with the answer sheets were put in sealed envelopes and given to the teachers that would teach the selected students during the first period. These teachers after welcoming back the students, distributed the tests to students and told each student to complete the test. Before the commencement of the examination students were asked to read carefully the following instructions (see figure 3.2) that were located in the first page of the test.

Figure 3.2 *Instructions for DIRECT*

All light bulbs, resistors, and batteries are identical unless you are told otherwise. The battery is ideal, that is to say, the internal resistance of the battery is negligible. In addition, the wires have negligible resistance. Below is a key to the symbols used on this test. Study them carefully before you begin the test.



To insure the validity of the research procedures the following measures were taken:

- Students didn't know beforehand that they will be asked to complete the diagnostic test, in order to ensure that their answers will reflect their knowledge during that specific time and won't be a result of preparation.

- It was made clear to the students that the diagnostic test and interviews are anonymous, that their completion is made exclusively for research purposes and will not influence in any way their performance in the course of Physics.
- During the completion of the test students weren't allowed to collaborate with each other, or ask clarifications from the supervisor about the test.
- Due to the fact that the test would be used again at a later time, after a team of students completed the test, both tests and answer sheets were collected, and placed in a sealed envelope, to ensure that students won't keep copies of the test and become familiar with the questions, or pass them to other students.

After test completion, the sealed envelopes containing the tests and the answer sheets were given to the researcher by the teachers, and the classification of students' answers begun.

3.6.2 PART II

The second part of the study focused on measuring the effect of CCM-based activities on students' misconceptions about simple electric circuits.

The class of the 15 second grade (11th grade level) students chosen as the research sample, completed DIRECT concurrently with the rest of the students during the survey conducted for the first part of the study. After the data from the survey were analysed, a sub-sample of five students was interviewed, and their answers were recorded and later transcribed.

Afterwards, and after taking into account the data obtained from the literature review (see chapter 2), the findings from our baseline research (see chapter 4) and the instructional objectives of the curriculum (see appendix A), the researcher made the following decisions with regards to the content and the reference framework of our instructional interventions. These decisions are listed below:

- The instructional activities were designed using Stepan's 6-stage Conceptual Change Model (see figure 2.7). The researcher when designing the worksheets adopted the methodology used by Stepan (2008) in his book *“Targeting Students' Physical Science Misconceptions Using the Conceptual Change Model”*.

- All instructional activities were designed to be performed in the physics laboratory. The researcher after consulting the related literature (Zacharia & Anderson, 2003; Zacharia, 2007; Jaakkola & Nurmi, 2008; Zacharia & Olympiou, 2010), chose to use ICT tools such like PowerPoint slides, and simulation software like Edison 4 and Virtual Labs Electricity, only when thought they would make a greater impact on students' misconceptions than laboratory equipment, or objects from everyday life.
- During the implementation of all the activities students worked in groups. In order to ensure that students will cooperate without problems for a prolonged period of time the researcher followed Koumaras's advice and formed mixed-ability (heterogenous) groups (Koumaras, 1989). The researcher in order to form these groups divided the class into three levels of attainment (above average, average, below average) according to the students' achievement scores from previous years as well as achievement scores on the pre-test. Afterwards the researcher used friendship patterns to ensure that every group consisted of as many close friends but with different level of attainment as possible, because students in friendship groups tend to have significantly more involvement in the group and better performance than students in ability groups (Chauvet & Blatchford, 1993).

After the completion of the curriculum design of the activities, the implementation phase begun. Due to time constraints, lab availability and other extraneous factors such as a sudden illness of the researcher, the curriculum project was not completed in its entirety. Only the subjects 6.1 though 6.8 were taught, and the subjects 6.9 through 6.11 (see appendix A, p.95), were omitted.

At the end of the implementation phase, students were tested again using DIRECT, and the same students that were interviewed during the pre-test, were interviewed again and their answers were recorded and later transcribed. Because it was impossible to translate and present our CCMBI project in its entirety we chose the example of application method (Koumaras, 1989). In the section below the design and implementation of a module devoted to resistor combinations is presented as an example.

3.6.3 EXAMPLE OF APPLICATION

3.6.3.1 INTRODUCTION

This section aims to demonstrate our CCMBI strategy in terms of design and level of implementation. The specific module has been chosen because a) it was designed to treat some of the misconceptions that appeared most frequently among STVE students and b) it was adopted from the book "Targeting Students' Physical Science Misconceptions Using the Conceptual Change Model" by J. Stepan, so its translation required the least amount of effort and c) its implementation in the physics laboratory included all six phases of Stepan's CCM. The title of this module is: "Resistor Combinations" and its position in the curriculum is presented in Appendix A, p.97.

We note here that for consistency purposes, we decided that it was appropriate to repeat some information already presented in previous chapters.

3.6.3.2 EXAMPLE OF APPLICATION OF THE UNIT "RESISTOR COMBINATIONS"

First session (45 minutes)

For a short time period (2-3 minutes), the teacher reminds students what they have seen and done during the previous session. Then students form small groups (3-4 students) and the teacher distributes Part I of Worksheet #7 (see Appendix B) to them. Students are requested to complete steps 1 and 2 of Activity 1 of the worksheet (see Appendix B, p.99), which asks them to predict which of the bulbs depicted in a Prediction Sheet (see Appendix B, p.101) will light and explain their reasoning (commit to a position or outcome phase see figure 2.7).

A brief discussion among group members follows, and each group's representative presents his/her group's ideas to the whole class (expose beliefs phase see figure 2.7).

Each group then sits in front of a computer running Edison 4 demo simulation software and sets up the circuits depicted in the Prediction Sheet. Group members exchange views among them and answer the questions in step 3 of the worksheet (see Appendix B, p.99). The teacher circulates around the room, listens to and monitors discussions between group members, and provides technical assistance only when asked. He also answers questions of clarification if requested (confront beliefs phase see figure 2.7).

Next, students are requested to answer the questions in steps 4 (accommodate the concept phase) and 5 of the worksheet (extend the concept phase), and copy step 6 of the worksheet to their workbook (see Appendix B, p.100). Teacher circulates around the room, listens to and monitors discussions between group members, and provides technical assistance only when asked. He also answers questions of clarification if requested and inform students about the time remaining. Finally when the bell rings, students deliver their worksheets to the teacher and leave the lab. When at home, students complete in their workbook the step 6 of the worksheet (go beyond phase see figure 2.7).

The purpose of the last three questions is to provide information to the teacher whether students' acts during the session made them change their minds about which circuits work. Also student's answers to these questions intend to inform the teacher whether the students are able to: a) understand the conditions under which a short circuit occurs b) give a definition of short circuit and c) provide examples of where short circuits occur in our everyday lives and what are the effects of short circuits.

When at home, the teacher studies students' responses to worksheet questions and notes which are the initial students' opinions about which circuits work and how they were formed at the end of the session. The feedback the teacher gets from the students helps him to organize the next session and if necessary, to make amendments to the worksheet he intends to use, or to the content of the conversation between him and the students.

Second session (90 minutes)

For a short time period, the teacher reminds students what they have seen and done during the previous session, checks whether students have done their homework, and asks 1-2 students to present their homework to the whole class. Then students form the same groups as in the previous session and the teacher distributes Part II of Worksheet #7 (see Appendix B) to them.

Students are then requested to complete part A of Activity II (see Appendix B, pp.102-103), where they are asked: a) to make a drawing of set-ups that will light two light bulbs at the same time by using the least number of batteries and wires, as well as provide reasons for their drawings and explain if (and why) there will be a difference in the outcome with the different set-ups, b) share their drawings and explanations in their small group and the whole class and c) test their ideas by materializing their drawings.

By testing different configurations, students come to a point where they realize that only two set-ups will light two bulbs connected in a single battery, and the brightness of the bulbs is different in each set-up. The teacher uses the opportunity and tells the students that these two different connections of two light bulbs with a single battery are called "connection in series" and "connection in parallel".

Students next investigate the behaviour of series and parallel circuits in a systematic manner. They are requested to complete steps 1 and 2 of part B of Activity II (see Appendix B, p.103) of the worksheet, which asks them to predict which of the bulbs depicted in a Prediction Sheet (see Appendix B, p.105) will light and explain their reasoning. Also they have to predict what will happen if one of the bulbs is removed from the set-up and explain their predictions. A brief discussion among group members follows, and each group's representative presents his/her group's ideas to the whole class.

Each group then sits in front of a computer running Edison 4 demo simulation software and sets up the circuits depicted in the Prediction Sheet. Group members exchange views among them and answer the questions in step 3 of the worksheet (see Appendix B, p.103). The teacher circulates around the room, listens to and monitors discussions between group members, and provides technical assistance only when asked. He also answers questions of clarification if requested.

By completing steps 1, 2 and 3 of part B of Activity II (see Appendix B, p.103), students using a procedure that they have become familiar with, are forced to conclude that the current through a light bulb depends on the configuration of the circuit. The concept of equivalent resistance is then introduced. The students find that this quantity depends on the configuration and not merely on the number of elements or branches.

After investigating the behaviour of different configurations of bulbs connected to a single battery, students are now ready to complete step 4 part B of Activity II (see Appendix B, p.104), where hopefully they will be able to make statements like "individual bulbs connected in parallel directly across an ideal battery are brighter than the same two bulbs connected in series with an ideal battery" or "series electric circuits have elements arranged one after another along the circuit. The current therefore flows through each element in turn. If one element is removed then the circuit is broken" and "parallel electric circuits have elements arranged side by side (in *parallel*) along the circuit. The current therefore flows through each element at the same time. If one element

is removed then the circuit is not broken because current can still flow through the parallel route".

Next, students are requested to answer the questions in step 5 of part B of Activity II, and copy step 6 of the same part to their workbook (see Appendix B, p.104). The purpose of the last two steps questions is to make students think of the applications of series and parallel circuits, and understand if they had previous experience with series or parallel circuits. They are encouraged to search this topic more in depth at home, and bring at the next session examples, questions, or problems on electrical circuits they may be interested in pursuing.

Finally when the bell rings, students deliver their worksheets to the teacher and leave the lab. When they get home, students have to complete step 6 of the worksheet in their workbook.

When at home, the teacher by studying students' responses to worksheet questions, is able to determine each student's level of understanding about which circuits work and the outcomes of different circuit combinations. This feedback helps him to organize the next session and if necessary, to make amendments to the worksheet he intends to use, or to the content of the conversation between him and the students.

3.7 SUMMARY OF THE CHAPTER

The chapter begun by detailing the research approach used and the conditions under which the various stages of research were carried out (section 3.2). Next, it dealt with the research population and sample (section 3.3), data collection instruments (section 3.4), ethical considerations (section 3.5). The chapter also detailed the research methodology, covered how data were derived from primary and secondary sources, and finally an example of application of the strategy used was described (section 3.6).

CHAPTER 4: DATA ANALYSIS AND INTERPRETATION

4.1 INTRODUCTION

In the previous chapter, the methodology used in this study was outlined, the participants who formed the sample for the study, the course design were introduced, and the methodological norms were discussed.

This chapter presents the data analysis and interpretation in the following structure:

- Section 4.2 will present and interpret the results of the first part of the study
- Section 4.3 will present and interpret the results of the second part of the study.

Finally a summary of the chapter is presented.

4.2 PART I

The purpose of this part of the study was not only to evaluate students' achievement in the field of simple electric circuits, but mainly to assess and commit to paper students' misconceptions in this field of study. Having that in mind, the responses that students gave were not categorized only as correct or erroneous, but three categories of answers were created: a) correct answer, b) misconception and c) other (Paraskeyas & Alimisis, 2007).

In the first category we classified the correct answers according to the answer key given by DIRECT developers P.V. Engelhardt and R.J. Beichner.

In the second category the answers that express students' alternative perceptions that contradict scientific knowledge were classified. This category was later analysed into subcategories based on the specific misconception that corresponds to the answer that students gave.

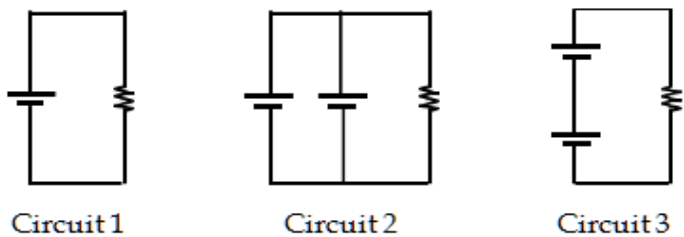
In the third category we classified the remainder of the answers that students gave and didn't fall into any of the first two categories. For instance in Question 12 (Figure 4.1) answer (D) was classified in the first category, while answers (A), (B) and (C) were

classified in the second category. Answer (E) didn't fall into any of the first two categories so it was classified in the third category.

Figure 4.1 DIRECT Question 12

12) Consider the power delivered to each of the resistors shown in the circuits below. Which circuit or circuits have the LEAST power delivered to them?

(A) Circuit1
 (B) Circuit2
 (C) Circuit3
 (D) Circuit1 = Circuit2
 (E) Circuit1 = Circuit3



Circuit 1 Circuit 2 Circuit 3

For comparison reasons the results of the present study were compared with the results of a study conducted in 2002 by P.V. Engelhardt and R.J. Beichner, where the researchers surveyed students' understanding of simple electric circuits. The sample consisted of students from Canada, Germany, and the United States (Engelhardt & Beichner, 2004).

The data obtained, were analysed in a variety of ways. We checked the students' achievement in each of the instructional objectives that DIRECT examines. These results were compared with the results of Engelhardt and Beichner's study. The findings are analytically presented in the Table 4.1 below.

Table 4.1 Objectives for DIRECT and mean rate of students' achievement in each objective

Objective	Question No	Avg. Percentage Correct %	
		STVE Students	USA - Canada - Germany High School Students
1	10, 19, 27	41	51
2&3	9, 18	51	57
1-3	27	44	69
4	5, 14, 23	30	25
5	4, 13, 22	45	45
6	2, 12	25	31
7	3, 21	46	52
8	8, 17	38	47
9	1, 11, 20	22	18
10	7, 16, 25	39	35
11	6, 15, 24, 28, 29	28	28
8&11	26	26	37

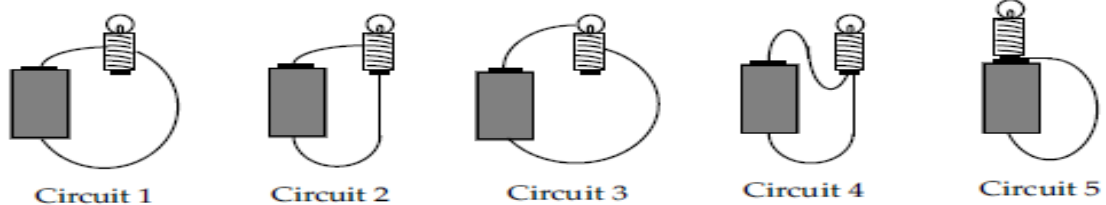
By studying the results it becomes obvious that STVE students' achievement is in general terms similar with that of students from other countries. Significant divergences were found only in question No 27 (objectives 1-3 combined), in questions No 8 & 17 (objective 8) and in question 26 (objectives 8 & 11 combined). The divergence observed in the mean rate of students' achievement in objective 1 is mainly due to the range of divergence in students' achievement in question 27, so no further discussion will be conducted regarding this issue.

In question No 27 that examines students' ability to identify a complete circuit, a short circuit and to understand the functional two-endedness of circuit elements, results indicate that more than 55% of STVE students failed to predict that only the bulb in Circuit 2 (Figure 4.2) will light.

By analysing the distribution of the answers that students gave to this question, we conclude that the reason for this failure is mainly due to the fact that students don't know where the contacts of the bulb are located. They believe that if we attach two leads connected to a battery anywhere in the surface of the bulb, then the bulb will illuminate.

Figure 4.2 DIRECT Question 27

27) Will all the bulbs be the same brightness?



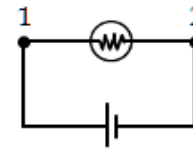
- (A) Yes, because they all have the same type of circuit wiring.
- (B) No, because only Circuit 2 will light.
- (C) No, because only Circuits 4 and 5 will light.
- (D) No, because only Circuits 1 and 4 will light.
- (E) No, Circuit 3 will not light but Circuits 1, 2, 4, and 5 will.

Questions No 8 & 17 (objective 8, Figure 4.3) examine students' ability to understand and apply conservation of current to a variety of circuits. Here the majority of the students adopt the "weakening current" model mentioned in section 2.2.

Figure 4.3 DIRECT Questions 8 & 17

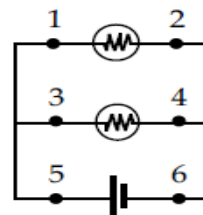
8) Compare the current at point 1 with the current at point 2. At which point is the current LARGEST?

- (A) Point 1
 (B) Point 2
 (C) Neither, they are the same. Current travels in one direction around the circuit.
 (D) Neither, they are the same. Currents travel in two directions around the circuit.



17) Rank the currents at points 1, 2, 3, 4, 5, and 6 from HIGHEST to LOWEST.

- (A) 5, 3, 1, 2, 4, 6
 (B) 5, 3, 1, 4, 2, 6
 (C) 5 = 6, 3 = 4, 1 = 2
 (D) 5 = 6, 1 = 2 = 3 = 4
 (E) 1 = 2 = 3 = 4 = 5 = 6



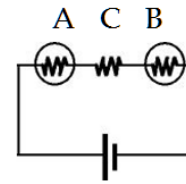
This divergence was expected as it has already been documented in a similar study conducted among Greek students by Koumaras et al. (1990). In that study only 35% of the students answered that the value of electric current remains unaltered when it travels through a light bulb or a resistor. The reason of this divergence is caused by the fact that students learn from their parents, their peers, even from the mass media that what is "consumed" when we turn on an electric device is not electric energy, but electric current (Koumaras *et al.*, 1990; Koltsakis & Pierratos, 2006). This misconception is so widespread, that if we put in Google search engine the phrase "κατανάλωση ρεύματος" (current consumption in Greek), it returns about 125.000 results!

An interesting finding emerges from studying the distribution of students' responses to question 26 (objectives 8&11, Figure 4.4). The majority of the students selected answer C as the answer they thought was correct, which means that STVE students think that if we increase the resistance of a resistor located between two bulbs, then the bulbs' illumination will also increase. On the contrary, the majority of their counterparts from other countries selected a more "predictable" answer as the correct answer, that is answer A.

Figure 4.4 DIRECT Question 26

26) If you increase the resistance C, what happens to the brightness of bulbs A and B?

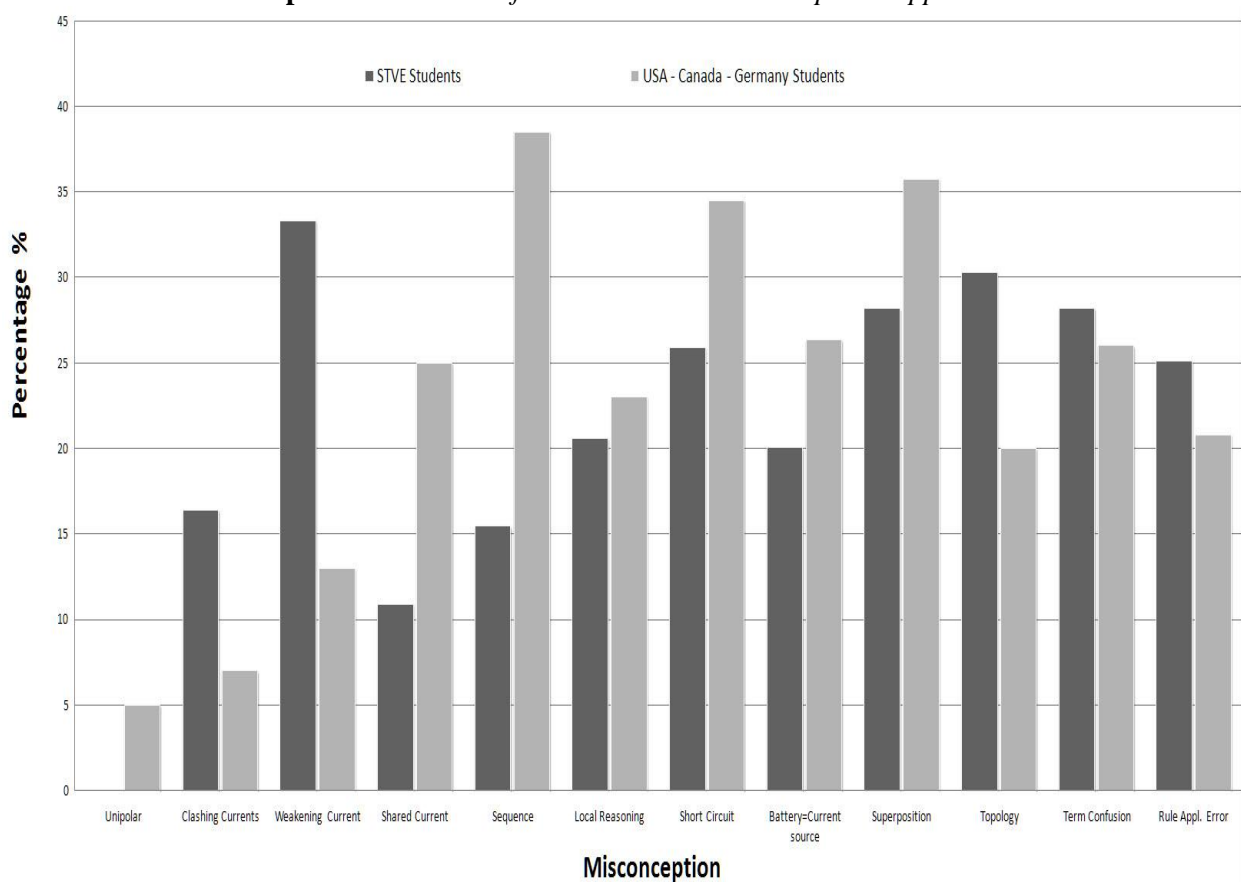
- (A) A stays the same, B dims
- (B) A dims, B stays the same
- (C) A and B increase
- (D) A and B decrease
- (E) A and B remain the same



In the remainder of the instructional objectives, Cypriot students share their success or failure, with their counterparts from other countries.

Afterwards a frequency analysis of students' misconceptions was performed. This action was deemed necessary in order to make a comparison of the STVE students' rate of misconceptions appearance, with the corresponding rate in the Engelhardt and Beichner's study and find prospective divergences between the two studies. The results are presented in Graph 4.1 that follows, together with their equivalents obtained from Engelhardt and Beichner's study.

Graph 4.1 Mean rate of STVE students misconceptions appearance



What we observe by studying the graph is that none of the STVE students adopts the unipolar model (section 2.2), while on the contrary, it is adopted by 5% of the students in Engelhardt and Beichner's study. This finding needs to be further investigated at a later time.

A significant divergence in the appearance rate of the clashing currents and the weakening current models that were mentioned in section 2.2 is also observed, a fact which we have previously pointed out in this section. This could be caused by the erroneous way that students receive information related with electric phenomena from their social environment. Expressions commonly used in Cyprus such as "he was knocked out by current" or "don't waste current", contribute to the development of erroneous perceptions, that are difficult to be eliminated with formal teaching (Koumaras *et al.*, 1990).

A divergence is also observed in the percentage of STVE students that have problems identifying circuits that are topologically equivalent. Caillot (1984) believes that students have some form of prototypical view of what constitutes two resistors in series or parallel in a geometrical rather than topological sense. Taking Caillot's view into account, maybe the percentage of STVE students that have this form of prototype view rather than the exemplar or classical view of concept representation is higher than the norm.

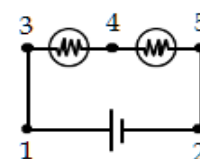
An interesting fact that will be further investigated is the ascertainment that the percentage of appearance of the shared currents and the sequence models among STVE students is much smaller than that of their counterparts from other countries.

Another finding that also requires further investigation is the reasoning with which STVE students responded in question 6 (Figure 4.5).

Figure 4.5 *DIRECT Question 6*

6) Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown below from HIGHEST to LOWEST.

- (A) 1 and 2; 3 and 4; 4 and 5
- (B) 1 and 2; 4 and 5; 3 and 4
- (C) 3 and 4; 4 and 5; 1 and 2
- (D) 3 and 4 = 4 and 5; 1 and 2
- (E) 1 and 2; 3 and 4 = 4 and 5



In this question 47,3% of students selected the answers (C) and (D). That means that STVE students consider that the potential difference between the points located above the battery is higher than the potential difference between the poles of the battery.

An assumption was that perhaps did STVE students confuse the term "*πτώση τάσης*" (voltage fall) that is synonym to *potential difference* in Greek language. So maybe they perceive that in order to have "voltage fall", the potential difference between points 3 and 4 should be the highest because point 3 is located in the top left corner and point 4 follows. So as we travel further in the direction of current flow the potential difference will gradually "fall".

4.3 PART II

The purposes of this part of the study were a) to find out if the misconceptions of STVE students that have been uncovered and classified in the first part of the study, have changed towards scientifically accepted ideas after the implementation of the four-week instructional unit taught using CCMBI and b) to measure the effectiveness of Conceptual Change Model Based instructional activities on students' misconceptions about simple electric circuits. So the quantitative and qualitative data that were collected during this part of the study were analysed having the aforementioned purposes in mind. The results of this analysis are presented below, together with an interpretation.

4.3.1 QUANTITATIVE DATA

The data obtained from the pre-test and post-test items were classified using the same procedure described earlier in the beginning of this section and analysed in a variety of ways.

At first the students' responses were classified as either correct (1 point) or incorrect (0 points) and the test scores in both pre-test and post-test were calculated. The results are presented in the Table 4.2 below.

Table 4.2 *Students' pre-test and post-test scores*

Student No.	Pre Test Score (%)	Post Test Score (%)
7358	48	76
7370	31	63
7473	41	55
7381	24	63
7482	51	80
7361	17	56
7374	37	45
7385	21	45
7380	55	63
7384	14	56
7642	55	80
7641	35	63
7449	38	62
7393	28	60
7388	27	70

4.3.1.1 Paired Samples t-test

A paired samples t-test was used to test for significance between pre-test and post-test scores. A paired samples t-test is used when describing change in the scores of a single group on the same variables or exposed to two measures over time, as in a pretest-posttest design (Thorne & Giesen, 2003).

SPSS Output

Following in Table 4.3 is the output of the paired samples t-test. We compared the mean test scores before (pre-test) and after (post-test) the students completed the course on electricity. First, we see the descriptive statistics for both variables.

Table 4.3 *Pre-test and Post-Test Paired Samples Statistics*

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PRE_TEST	34.87	15	13.510	3.488
	POST_TEST	62.52	15	10.631	2.745

We observe that the post-test mean scores were higher. This means that student performance has improved after the implementation of the conceptual change-based activities.

Next, in Table 4.4, we see the correlation between the two variables.

Table 4.4 *Pre-test and Post-Test Paired Samples Correlations*

	N	Correlation	Sig.
Pair 1 PRE_TEST & POST_TEST	15	.601	.018

The correlation shows that 60% of the students that performed better than the others on the pre-test also performed better than the other students on the post-test.

Finally, in Table 4.5, we see the results of the paired samples t-test. This test is based on the difference between the two variables. Under "Paired Differences" we see the descriptive statistics for the difference between the two variables. To the right of the Paired Differences, we see the t value, degrees of freedom, and significance.

Table 4.5 *Pre-test and Post-Test Paired Samples t-test*

		Paired Differences							
		Mean	Std. Deviation	Std. Error	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	PRE_TEST - POST_TEST	-27.651	11.081	2.861	-33.788	-21.515	-9.665	14	.000

The t-value is -9.665. We have 14 degrees of freedom and the Sig. (2-tailed) is .000.

From the significance value we observe that there was a significant difference between pre-and post-test scores.

4.3.1.2 Independent Samples t-test

Since five students were interviewed after each of the two tests, they effectively had another "treatment". So an independent samples t-test was performed to determine whether there was a statistically significant difference between the group of students that were interviewed and the group of students that were not. Initially in Table 4.6 we see the descriptive statistics for both groups.

Table 4.6 Pre-test and Post-Test Independent Samples Statistics

	INTERVIEW	N	Mean	Std. Deviation	Std. Error Mean
PRE_TEST	YES	5	35.2000	15.12283	6.76314
	NO	10	34.6000	13.20101	4.17453
POST_TEST	YES	5	67.0000	10.44031	4.66905
	NO	10	60.2000	10.65416	3.36914

We observe that although the students' pre-test mean scores in both groups are almost the same as a result of our careful selection (see section 3.4.2), the post-test mean scores of students that were interviewed are slightly higher. This means that the students that were interviewed performed slightly better in the post-test than the students that were not.

Following in Table 4.7 are the results of the post-test independent samples t-test. The results of this test indicate if there was a significant difference between the two groups' post-test scores.

Under "Levene's Test for Equality of Variances" we see whether the variability of each group is approximately equal. Under "t-test for Equality of Means" and starting from the left we see the t value, degrees of freedom, and significance.

Table 4.7 Post-Test Independent Samples t-test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
POST TEST	.070	.795	1.172	13	.262	6.80000	5.79973	-5.72957	19.32957
			1.181	8.255	.270	6.80000	5.75770	-6.40615	20.00615

The significance value of Levene's test is .795. This means that the variability of the two groups is equal, and the output of the row labelled "Equal variances assumed" will be discussed.

The t-value is 1.172. We have 13 degrees of freedom and the Sig. (2-tailed) is .262.

From the significance value we observe that there was no significant difference between the post-test scores of the group of students that were interviewed and the group of students that were not. Hence, from now on, we will assume that these two groups' achievement and misconceptions follow similar patterns and we will not discuss their results separately.

4.3.1.3 Students' achievement and misconception analysis

In addition, we also checked was the students' achievement in each of the instructional objectives that DIRECT examines. The findings are analytically presented in the Table 4.8 below.

Table 4.8 Objectives for DIRECT and test results

Objectives	Question No	Avg. Percentage Correct		
		Pre test	Post Test	
Physical aspects of DC electric circuits (objectives 1-5)				
1	Identify and explain a short circuit	10, 19, 27	42	87
2	Understand the functional two-endedness of circuit elements.			
3	Identify a complete circuit and understand the necessity of a complete circuit for current to flow in the steady state	9, 18	40	83
Objectives 1–3 combined		27	53	100
4	Apply the concept of resistance including that resistance is a property of the object and that in series the resistance increases as more elements are added and in parallel the resistance decreases as more elements are added.	5, 14, 23	33	82
5	Interpret pictures and diagrams of a variety of circuits including series, parallel, and combinations of the two.	4, 13, 22	40	89
Circuit layout (objectives 1–3, 5)			41	89

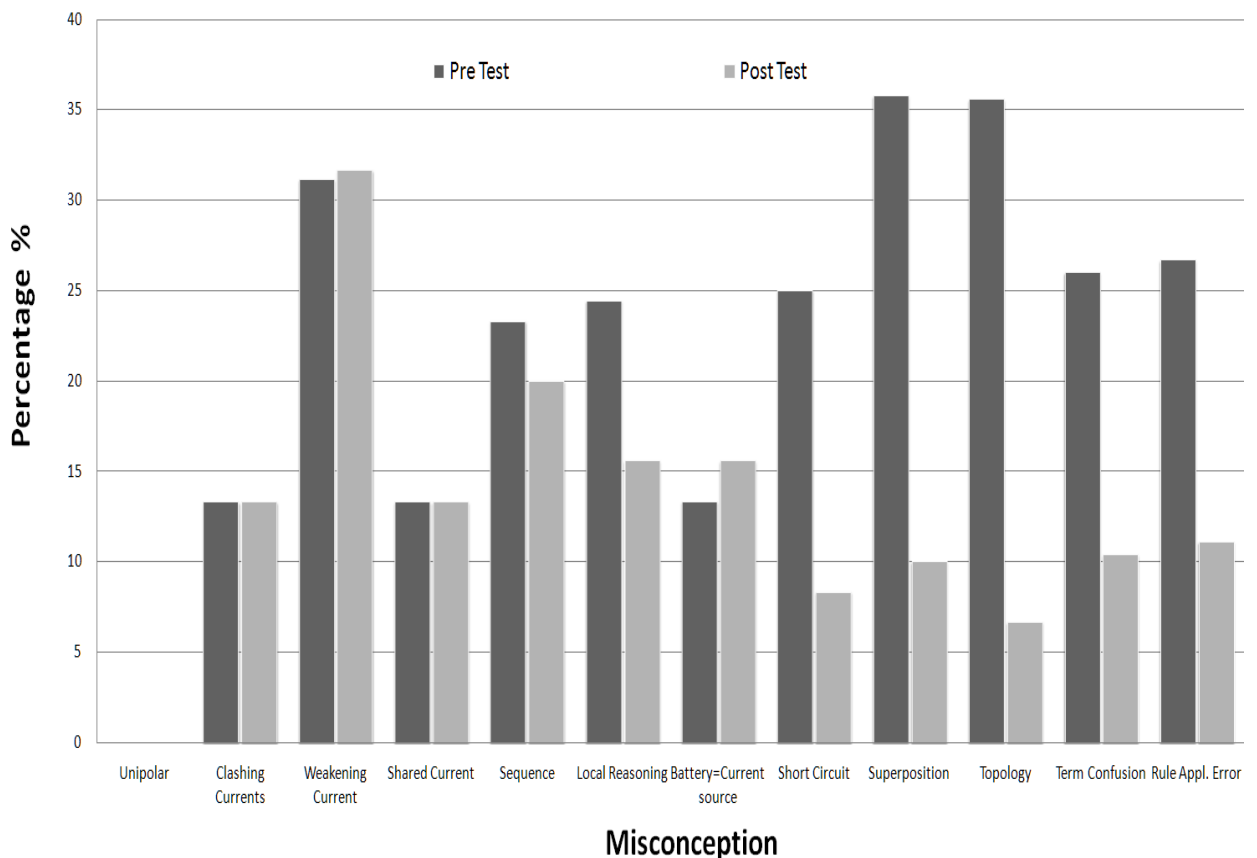
Energy (objectives 6–7)				
6	Apply the concept of power (work done per unit time) to a variety of circuits.	2, 12	23	30
7	Apply a conceptual understanding of conservation of energy including Kirchhoff's loop rule and the battery as a source of energy.	3, 21	53	60
Current (objectives 8-9)				
8	Understand and apply conservation of current (conservation of charge in the steady state) to a variety of circuits.	8, 17	50	53
9	Explain the microscopic aspects of current flow in a circuit through the use of electrostatic terms such as electric field, potential differences, and the interaction of forces on charged particles.	1, 11, 20	13	67
Potential difference (Voltage) (objectives 10-11)				
10	Apply the knowledge that the amount of current is influenced by the potential difference maintained by the battery and resistance in the circuit.	7, 16, 25	36	40
11	Apply the concept of potential difference to a variety of circuits including the knowledge that the potential difference in a series circuit sums while in a parallel circuit it remains the same	6, 15, 24, 28, 29	32	35
Current and Voltage (objectives 8 & 11)		26	27	53

Misconceptions Analysis

Following the procedure that we have used in Part I, a frequency analysis of students' misconceptions in both pre-test and post-test was performed. The results are presented in Graph 4.2 that follows in the next page.

What we observe by studying the graph, is that percentage of the students that adopt the clashing currents and the shared current model remained unaltered even after instruction.

We also observe that instruction not only failed to decrease the percentage of students that adopt the weakening current model, but on the contrary this percentage increased slightly in the post-test analysis.

Graph 4.2 Rate of pre-test post-test misconceptions appearance

An increase is also observed in the percentage of students that consider the battery as a constant current source rather than a constant potential difference source.

Instruction was effective at reducing the number of students that adopt the sequence and local reasoning models but only slightly.

The percentages of students that adopt the short circuit, superposition, and topology dropped significantly after instruction. There is also a significant decrease in the percentage of students that confuse the terms that occur in simple electric circuits or misapply a rule governing circuits.

After consulting the test answer key supplied by Engelhardt and Beichner the impact of CCMBI based activities is again confirmed, as the distracters that examine the short circuit, superposition, topology, term confusion and rule application error models were located in the items that examined the objectives that were taught using CCMBI based instruction.

4.3.2 QUALITATIVE DATA

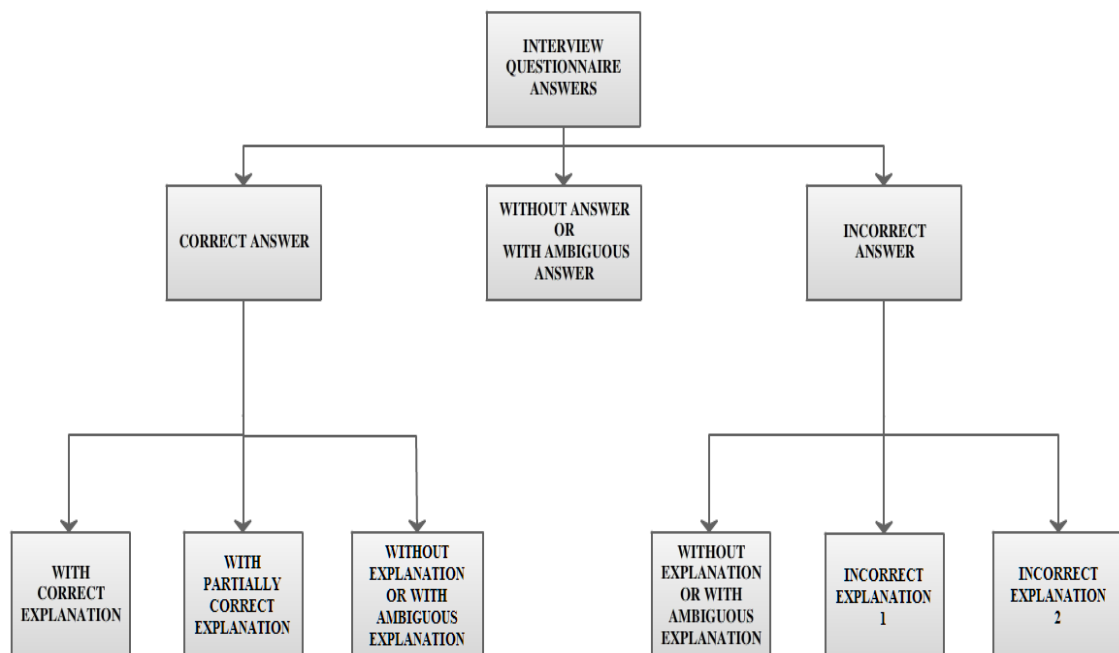
4.3.2.1 INTERVIEWS

4.3.2.1.1 Introduction

Five participants were interviewed after they have written their pre-test. The same were interviewed after they have written their post-test. In this section, the results from the analysis of these participants' interviews are presented. As we have described earlier in section 3.4.1.2, the participants were asked to answer fourteen questions—both written and orally—and their answers were recorded.

After the transcription of the recorded data, the answers that students gave were analysed using the approaches which require the definition of scientifically complete response (nomothetic) and the classification of explanations in certain categories (ideographic) (Driver & Erickson, 1983; Küçüközer & Kocakulah, 2007). These categories are shown in Figure 4.6.

Figure 4.6 *Analysis of Interview Questions*



In order to classify students' answers, different levels under two categories were determined. These categories comprised of the classification of similar explanations that fall into the same level. Apart from these levels, ambiguous answers and empty lines without an answer constitute the other category. There was a discussion with a group of experienced teachers regarding the extent after which an explanation will be considered correct or partially correct, and also under which level an explanation to an incorrect answer will fall. These teachers analysed the students' responses and sent their opinions to the researcher. Their opinions were taken into account and the classification of the answers began.

Correct Answer Category

- a) With correct explanation: In this level we have included the responses in which students gave correct answers in the 'fixed-alternative' part of the question and also gave a scientifically accepted explanation in the 'open-ended' part of the question.
- b) With partially correct explanation: Responses involving correct answers in the 'fixed-alternative' part of the question, but correct and incorrect explanation sentences, or correct but incomplete explanations in the 'open-ended' part of the question, were categorized in this level.
- c) Without explanation or with ambiguous explanation: Responses involving correct answers in the 'fixed-alternative' part of the question, but with explanations in the 'open-ended' part of the question which are difficult to understand their meaning, explanations that have no relation with the questions and no explanation at all were considered to belong in this level.

Incorrect Answer Category

- a) Without explanation or with ambiguous explanation: Responses involving incorrect answers in the 'fixed-alternative' part of the question, with explanations in the 'open-ended' part of the question which are difficult to understand their meaning coincide with this level. Explanations that have no relation with the questions and no explanation at all also coincide with this level.

b) Incorrect Explanation 1: Responses involving incorrect answers in the ‘fixed-alternative’ part of the question, but with explanations focusing on the minority or majority of any circuit component and the way the circuit is connected in the ‘open-ended’ part of the question were categorized in this level.

c) Incorrect Explanation 2: Responses involving incorrect answers in the ‘fixed-alternative’ part of the question, but with explanations that could not be categorised in the two previous levels in the ‘open-ended’ part of the question, were categorized in this level.

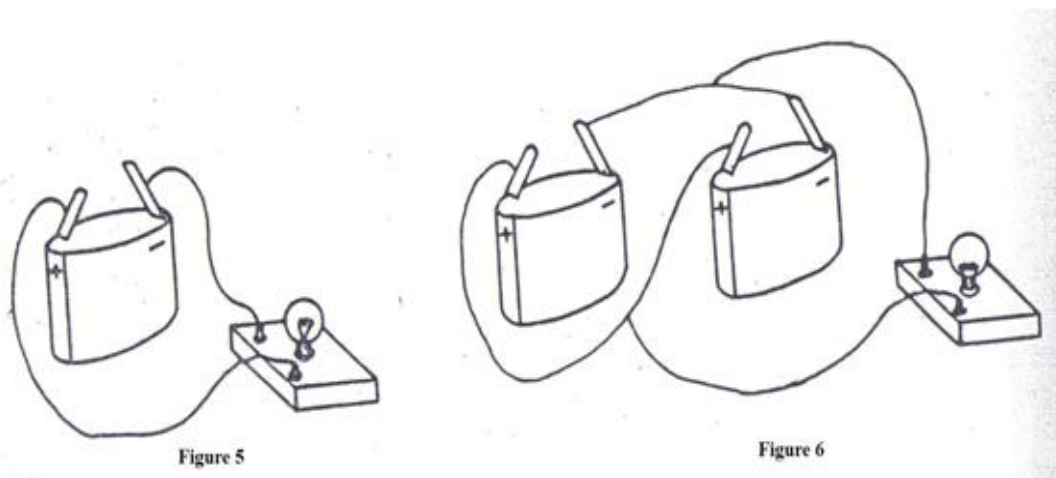
Without Answer or With Ambiguous Answer

Students who did not respond at all to the ‘fixed-alternative’ part of the questions or the answers that they gave in the ‘open-ended’ questions were completely irrelevant were put in this category.

Question 5 (Figure 4.7) is given as an example to explain the levels formed. This question is based on the concept of brightness of two identical bulbs one of which is connected with one battery and the other is connected with two batteries in parallel.

Figure 4.7 Interview Question 5

5. The bulbs, the batteries and the cables in figures 5 and 6 are identical to each other. The brightness of the bulb in figure 6 is greater, equal, or less than the brightness of the bulb in figure 5? Explain your answer.



Correct Answer : The brightness of the bulb in figure 6 is equal with the brightness of the bulb in figure 5.

- a) With correct explanation: "... because the batteries are connected in parallel, so the equivalent potential difference is the same in both figures"
- b) With partially correct explanation: "... because the amount of current that passes through and is consumed by the light bulb in figure 5 is also the same in figure 6"
- c) Without explanation or with ambiguous explanation: "... because the bulb is the same in both figures"

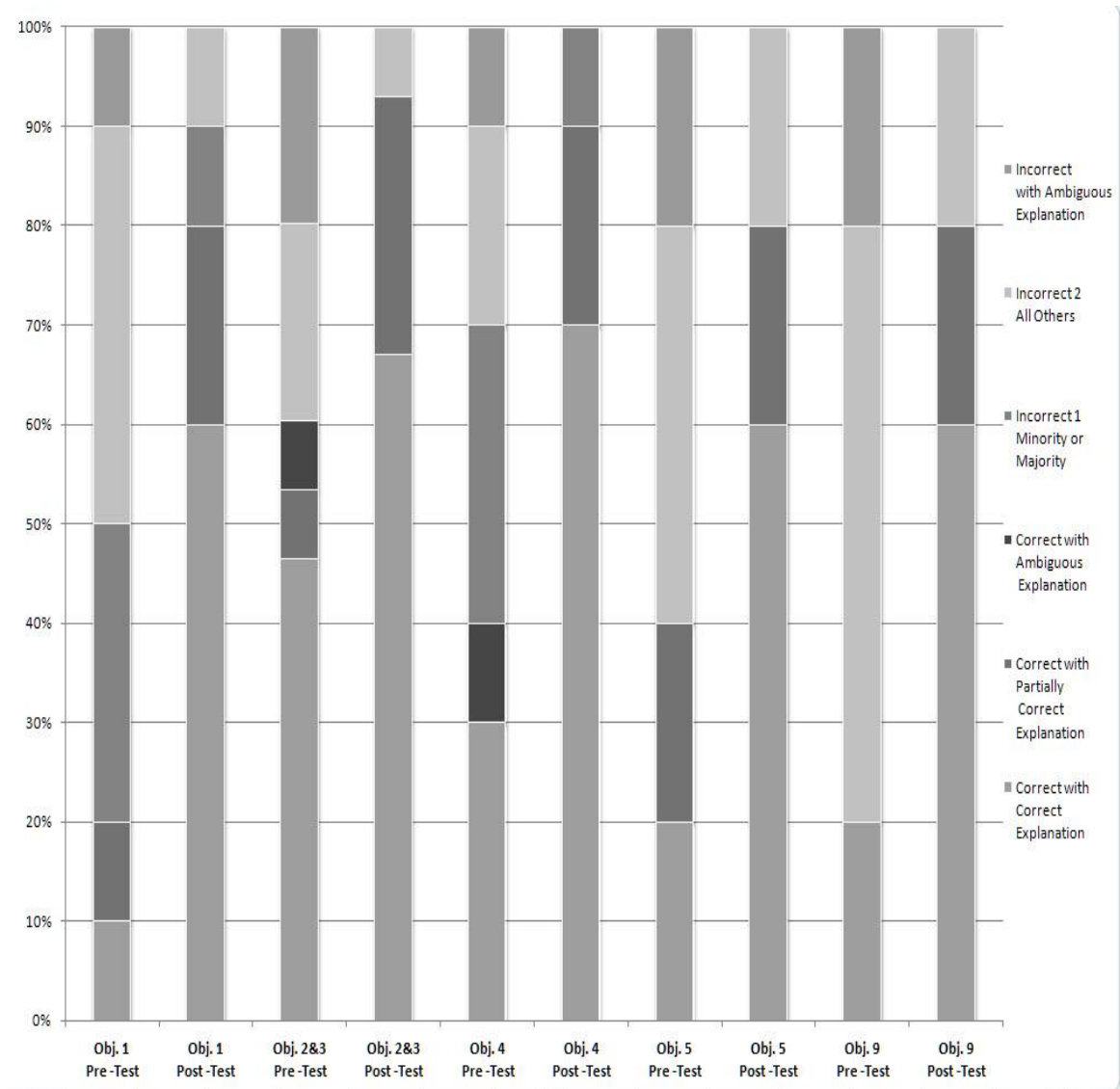
Incorrect Answers: The brightness of the bulb in figure 6 is greater than, or less than the brightness of the bulb in figure 5.

- a) Without explanation or with ambiguous explanation: "The brightness of the bulb in figure 6 is less than the brightness of the bulb in figure 5 because the leads are messed up"
- b) Incorrect Explanation 1: "The brightness of the bulb in figure 6 is greater than the brightness of the bulb in figure 5 because we now have two batteries instead of one"
- c) Incorrect Explanation 2: "The brightness of the bulb in figure 6 is greater than the brightness of the bulb in figure 5 because the bulb consumes more energy".

4.3.2.1.2 Qualitative data Analysis

During the course of the interview session that followed the post-test, it was evident that considerable advances had been made to students' repertoire of knowledge about the objectives DIRECT examines, that were taught using CCM-based instruction. This is illustrated in Graph 4.3 below and in a larger scale in Appendix D.

Graph 4.3 Mean rate per category of post pre-test post post-test interview questions CCMBI



We also sorted student responses to these interview questions according to statements reflecting students' misconceptions about simple electric circuits. The misconceptions that students used most often are represented by solid dots and the misconceptions that the students used less often are represented by hollow dots as suggested by Engelhardt and Beichner (2004). The results are presented in the Table 4.9 below.

Table 4.9 *Misconceptions found during classification of incorrect answers to interview questions. Solid dots indicate misconceptions encountered most often. Hollow dots indicate misconceptions encountered less often.*

0% ≤ ○ ≤ 20%, 21% ≤ ○ ≤ 40%, 41% ≤ ● ≤ 60%, 61% ≤ ● ≤ 80%, 81% ≤ ● ≤ 100%

Misconception	Description	Post Pre-Test Interview	Post Post-Test Interview
Unipolar	Only one lead that connects the battery with the light bulb is needed in order to light the bulb	N/E	N/E
Clashing Currents	Bulb illuminates due to two electric currents with opposite directions “collide” inside its interior	●	●
Weakening Current	Current value decreases as you move through circuit elements until you return to the battery where there is no more current left	●	●
Shared Current	Electric current is shared equally among the light bulbs that illuminate the same.	●	●
Sequence	Only changes before an element will affect that element	●	●
Local Reasoning	Current splits evenly at every junction regardless of the resistance of each branch	●	●
Short Circuit	Wire connection without devices attached to the wire can be ignored	●	○
Battery as current source	Battery supplies same amount of current to each circuit regardless of the circuit's arrangement	●	●
Battery Superposition	1 battery bulb shines X bright. 2 batteries, shines 2X bright regardless of bulb arrangement	●	●
Resistive Superposition	1 resistor reduces the current by X. 2 resistors reduce the current by 2X regardless of the resistor's arrangement	●	○
Topology	All resistors lined up in series are in series whether there is a junction or not. All resistors lined up geometrically in parallel are in parallel even if a battery is contained within a branch	●	○
Term Confusion I/R	Resistance viewed as being caused by the current. A resistor resists the current so a current must flow for there to be any resistance	●	○
Term Confusion I/V	Potential difference viewed as a property of current. Current is the cause of the potential difference. Potential difference and current always occur together	●	●
Rule application error	Misapplied a rule governing circuits. For example, used the equation for resistor in series when the circuit showed resistors in parallel.	●	○

The results from the analysis of the post pre-test and post post-test interview data not only came to confirm the results of the quantitative data analysis, but lead to interesting findings that we probably couldn't obtain from the quantitative data alone. These findings are presented below:

- a) Students before instruction were unable to give a proper definition of electric current. Their answers started with "electric current is an energy..." or "electric current is a force...". Only one student responded that "electric current is when electrons are moving through a wire". But after CCM-based instruction this situation was drastically changed as the majority of the interviewees defined electric current as " ... the rate at which electrons flow through a surface." This definition is not 100% scientifically correct, and may have been a result of our activities that relied on simulations where the moving particles were always electrons.
- b) Students after instruction although they were able to identify a short circuit, they couldn't in most of the cases, understand its effects. So when students were asked to answer question 9 (Figure 4.8) the majority of their answers were like this: "The battery in figure 10 will run down faster than the battery in figure 9 because in figure 9 there is no bulb to consume the current (or the energy) of the battery" (after pre-test). "The battery in figure 10 will run down faster than the battery in figure 9 because in figure 9 there is a short circuit so the energy will flow back to the battery " (after post-test).

Figure 4.8 Interview Question 9

9. The bulbs, the batteries and the cables in figures 9 and 10 are identical to each other. The battery in figure 9 will run down slower or faster than the battery in figure 10? Explain your answer.



Figure 9

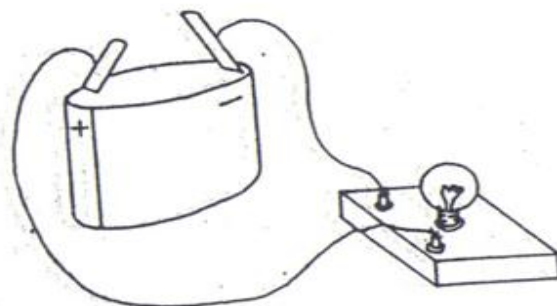


Figure 10

4.3.2.2 FIELD NOTES

Field notes analysis not only came to confirm the validity of the data gathered from the tests and interviews, but also may have revealed possible factors contributing to the observed differences.

For example observations from my field notes showed that students' interest during lab activities was rising after the completion of each class. While during the first class in which students started working in groups, I noticed that in each group of four students there were one or two students that appeared to be very interested in performing the lab activities, one or two students that seemed semi-interested, and one student that didn't seem to be interested at all, this situation was gradually changing. At the end of the course almost all of the students were interested in performing the lab activities and only two students were not completely interested. What was also depicted in my field notes, was the overall mood of the students during the course. Before course commencement and while performing in-class lectures only a handful of students were interested, while the remainder of the students didn't seem to pay attention to what I was saying or doing, they just had a set stare. Also while many times during in-class lectures when I asked students why they don't pay attention or why they came unprepared they came up with answers such as "I'm exhausted" or "We had an exam earlier in Math, so I've stayed up until late yesterday to study Math". These obstacles didn't seem to discourage them when performing lab activities.

Field notes also confirmed that students were able to develop a better understanding of electricity concepts when working in small groups with hands-on activities, rather than attending in-class lectures and solving textbook problems. For example in April 2010 I wrote in my field notes: "Students seem to have a greater ability to explain the microscopic aspects of current flow in a circuit than they did in the past. Not only did all the students manage to complete the activities on-time, but most of them had begun to write scientifically accepted explanations using the proper vocabulary".

Field notes analysis also showed that during CCM-based activities, students had gradually developed a sense of collegiality with group members cooperating in harmony, while some students were taking the role of "encourager" and helping other group members. Also when individual group members did not contribute to the work of the group as much as usual, the other group members forced that student to explain the

reason why he/she can't fulfil the task he/she was assigned to complete. If the explanation was not satisfactory, students asked me to exclude this student from the overall group grading.

Moreover students' significantly better performance in the post-test DIRECT and interview questionnaire items that examined the concepts taught using CCMBI, is perhaps due to the fact that during CCM-based instruction students were trained in writing scientific explanations by making a claim, supporting the claim with evidence, and then explaining this claim to other group members and to the whole class using the related scientific concepts.

4.4 SUMMARY OF THE CHAPTER

This chapter presented the data analysis and interpretation. The quantitative data were analysed using the Statistical Package for Social Sciences (SPSS) version 16.0. Descriptive and inferential statistics such as frequencies, tables, percentages and correlation tests were used in the data analysis and summaries. Relationships between variables were identified using frequencies, correlation and paired samples t-tests. The qualitative data were analysed by using nomothetic and ideographic approaches and the results of both qualitative and quantitative data were presented by using tables and graphs.

CHAPTER 5: SUMMARY AND CONCLUSION

5.1 INTRODUCTION

In the previous chapter the data obtained during the study were presented and interpreted. In the current chapter a summary of the study will be presented, the effectiveness of CCM model based instructional activities on students' misconceptions about simple electric circuits will be discussed and implications for instruction and further research will be suggested.

5.2 SUMMARY

The overall objective of this study was to develop CCM-based instructional activities that would effectively address STVE students' misconceptions about simple electric circuits and enhance their conceptual understanding.

In order to achieve the overall objective of the study, the literature from the fields of physics education, misconceptions about electricity, conceptual change theory and conceptual change teaching and learning were reviewed and the outcomes of this review helped the researcher to formulate the research questions and synthesise the theoretical framework to inform the design of the study.

The research questions that emanated from the overall objective of the study that we have outlined above were:

- 1. What are the misconceptions of Cypriot Secondary Technical and Vocational Education (STVE) students about simple electric circuits?**
- 2. Do these misconceptions change towards scientifically accepted ideas after the implementation of a four-week instructional unit taught using Conceptual Change Model Based Instruction (CCMBI)?**
- 3. What is the effect of Conceptual Change Model Based instructional activities on students' misconceptions about simple electric circuits?**

In order to answer the research questions, the researcher conducted a two part research project. Data analysis from the first part uncovered a pattern of misconception frequencies that was similar to that found in studies conducted in other countries (Engelhardt & Beichner, 2004) and previous years (Koumaras *et al.*, 1990), a fact that proves their universality and diachronicity. The most prevalent misconceptions among students were in descending order: weakening current, topology, term confusion, superposition, short circuit, rule application error and local reasoning.

Data analysis also showed that:

- STVE students adopt to a great extent the clashing currents and weakening current models, while on the contrary they don't seem to use the unipolar, the sequence and the shared current models (see section 4.2 & Graph 4.1).
- The students seem to ignore where the contacts of a bulb are placed (see section 4.2).
- Social environment plays an important role in the appearance of misconceptions resistant to formal teaching (see section 4.2).
- STVE students (30%) do not use mathematic equations in order to compute physical quantities such as equivalent resistance and power; they use the superposition model instead (see section 4.2 & Graph 4.1).
- STVE students (30%) seem to confuse common terms that occur in simple electric circuits such as electric charge or electric current with electric energy (see section 4.2 & Graph 4.1).

The findings from the first part of the study and synthesis of the theoretical framework guided the researcher in the creation and planning of CCM-based instructional activities. These activities were developed according to Stepan's CCM to target the most prevalent misconceptions among STVE students that were uncovered in the first part of the study. As the sample was very small the researcher could not rely on only quantitative analysis, so more methods of data collection were used. The effectiveness of the activities was measured by using data obtained by tests, interviews and field notes.

Paired samples t-test analysis for students' test scores, indicated that:

- There was a statistically significant difference between students' pre-test

($M=34.87$ $SD=13.51$) and post-test ($M=62.52$, $SD=10.63$) scores; $t(14)=-9.66$ $SD=11.08$, $p=0.000$ (Table 4.5).

- After CCMBI implementation students became more successful in the instructional objectives that were taught using CCMBI while on the other hand, there was not an important change on students' success in the remainder of the instructional objectives that DIRECT examines (Table 4.8).

Results of the frequency analysis of students' misconceptions in both pre-test and post-test (Graph 4.2) showed a significant percentage drop in the number of students having the misconceptions targeted by CCMBI and a negligible to non-existent difference in the rest of the misconceptions.

Results from the analysis of the post pre-test and post post-test interview data (Graph 4.3) showed a significant increase on students' understanding of scientific conceptions instructed using CCMBI. While the majority of students during post pre-test interviews answered the interview questions and justified their answers incorrectly, during post post-test interviews more than 80% of the students answered correctly in the interview questions that examined the objectives that were taught using CCMBI (see Graph 4.3). Moreover the percentage of students that gave a scientifically correct explanation in the justification of their answers was 60% or more in all of the objectives (see Graph 4.3). Analysis of post post-test interview data also uncovered some flaws in the design of the activities that made students in some cases develop erroneous perceptions, or to not understand a concept in its entirety (see section 4.3.2.1.2).

Data obtained from field notes confirmed the validity of the data gathered from the tests and interviews, and also showed that the CCMBI activities aroused students' interest and willingness during implementation. Moreover, it was noticed that students performed the assigned tasks voluntarily and gradually developed a sense of collegiality (see section 4.3.2.2).

5.3 LIMITATIONS OF THE STUDY

The present study is subject to limitations due to factors that affect the reliability and validity of the research instruments and the external validity of the research. These limitations are related to issues such as (Cohen *et al.*, 2000):

i. in tests :

- the time of day or the time of the school year,
- the temperature in the test room;
- the perceived importance of the test;
- the amount of guessing of answers by the students
- the underperformance of students whose motivation, self-esteem, and familiarity with the test situation are low

ii. in observations :

- the researcher might have become too attached to the group to see it sufficiently dispassionately;
- the presence of the researcher might have brought about different behaviours to the students

iii. in interviews :

- the tendency for the interviewer to see the respondent in his own image;
- misperceptions on the part of the interviewer of what the respondent is saying;
- misunderstandings on the part of the respondent of what is being asked.

Apart from these general texture limitations, this study is also subject to limitations due to financial restrictions and time scarcity, given that research was conducted at the researcher's own expenses and during a short time period.

In addition the participants of this study may have been representative of the available population, however, they may not have been representative of the population to which the researcher sought to generalize his findings, and could therefore be added to the limitations of the study (Cohen *et al.*, 2000).

5.4 CONCLUSION

The results of this study support that instructional activities utilizing Stepan's Conceptual Change Model is an effective means of significantly reducing the number of students holding misconceptions about specific scientific concepts -in our case about simple electric circuits. Therefore, Conceptual Change Model Based Instruction can be used effectively in physics classes to remedy students' misconceptions and increase their conceptual understanding. But as this model of instruction relies heavily on students' prior knowledge, investigating and categorizing students' misconceptions plays a very important role in the successful implementation of this model.

However, even if Conceptual Change Model Based Instruction caused predominantly positive changes in students' perceptions about simple electric circuits, and was more effective on helping students understand the scientific knowledge, some students maintained their misconceptions throughout the study. This means that there's no single panacea for remedying all students' misconceptions and if we truly want an education that addresses the needs of all students, a variety of teaching strategies must be used.

5.5 IMPLICATIONS

5.5.1 IMPLICATIONS FOR INSTRUCTION

This study provided evidence that Stepan's Conceptual Change Model used in the present study was effective in altering students' misconceptions and facilitated greater conceptual understanding. Thus, curricula should be developed and implemented to ensure that all students can have the opportunity to learn and understand concepts difficult to understand such as electricity.

However, conceptual change is a complex process, and promoting it requires the proper environment and equipment. Thus for the effective teaching of Physics, the researcher's

opinion is that the classrooms or the laboratories must be equipped with the necessary materials and computer equipment.

Effective conceptual change also requires a great amount of effort from the teachers and for this reason, the experiential training of teachers is more than essential, in order to achieve the long-sought objective of the replacement of students' misconceptions with scientifically acceptable ones.

5.5.2 IMPLICATIONS FOR FURTHER RESEARCH

Based on the findings of this study, the following implications for further research were developed:

- i. In this study the researcher due to unexpected reasons didn't teach the whole electricity unit using Conceptual Change Model Based Instruction. It would be interesting to investigate the effects of teaching the curriculum project in its entirety.
- ii. It would also be interesting to compare the long-term understanding of the students of the same grade who did and did not participate in the study.
- iii. The incorrect use of "current" in everyday speech in Cyprus (see section 4.2, p.54) could be another area to follow in future research.
- iv. This study focused solely on students enrolled in STVE. Further research should be conducted replicating this study at other secondary and post-secondary institutions. The results of this research would strengthen the validity of the findings of this study.
- v. The sample size and period of application should be increased so that the findings can be generalized.
- vi. The effects of Conceptual Change Model Based Instruction should be investigated in different physics topics apart from electricity.

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APPENDICES

APPENDIX A: COURSE SYLLABUS

UNIT 6		INSTRUCTIONAL OBJECTIVES	Periods
DIRECT ELECTRIC CURRENT AND DC RESISTIVE ELECTRIC CIRCUITS		The students will be able to:	
Subject			
6.1	Electric Current.	6.1.1. Explain the effect of applying potential difference across the ends of a metallic wire, to the free electrons inside the wire. 6.1.2. Define the electric current and recognise the charge carriers in various electrical conductors. 6.1.3. Identify a complete electric circuit, and indicate and explain the parts of the electric circuit and their function. 6.1.4. Define the electric current intensity and indicate the SI unit of measurement for the electric current intensity. 6.1.5. Define the potential difference between two points of an electric circuit and indicate the SI unit of measurement for the potential difference.	2
6.2	Sources of potential difference.	6.2.1. Identify that the sources of potential difference are devices that create a potential difference between their ends, and these ends are called poles. 6.2.2. Identify that the sources of potential difference are necessary in a circuit and without a source of potential difference there can be no continuous flow of electrical charges though the circuit.	1

6.3	Electrical Resistance.	<p>6.3.1. Identify that metals and other electrical conductors possess a crystal lattice structure that impedes the movement of the free electrons.</p> <p>6.3.2. Define the electrical resistance of an electrical conductor and indicate the SI unit of measurement for the electrical conductor.</p>	1
6.4	Variable resistor.	6.4.1. Identify that a variable resistor is an electrical component that can change its resistance manually and when connected properly in a circuit, alters the current or the potential difference between two ends of a circuit branch.	1
6.5	Direct electric current measuring instruments.	<p>6.5.1. Identify the instrument that is used to measure the intensity of the electric current and the proper way to connect this instrument in a circuit.</p> <p>6.5.2. Identify the instrument that is used to measure the potential difference between two points of an electric circuit and the proper way to connect this instrument in a circuit.</p>	1
6.6	Relation between electric current through, and potential difference between, two points of an electrical conductor. Ohm's Law.	<p>6.6.1. Identify that there is a direct relation between the electric current intensity that flows through an electrical conductor and the potential difference between the ends of the conductor. This relation depends on the material from which the electrical conductor has been made.</p> <p>6.6.2. Deduct from the $I=f(V)$ graph conclusions about the change of electrical resistance in line with the potential difference between the ends of an electrical conductor and therefore the temperature of the conductor.</p> <p>6.6.3. Formulate Ohm's law.</p>	2
6.7	Resistance of a given resistor. Resistor characteristics and marking of production resistors.	<p>6.7.1. Identify the factors which the resistance of an ohmic resistor depends on.</p> <p>6.7.2. Define the resistivity of an ohmic conductor.</p> <p>6.7.3. Experimentally investigate the factors which determine the resistance of an ohmic conductor.</p>	2

6.8	Resistor Combinations in Series & in Parallel	<p>6.8.1. Define the equivalent resistance of a set of resistors that are located between two points A and B.</p> <p>6.8.2. Calculate the equivalent resistance of two or three resistors connected in series or in parallel.</p> <p>6.8.3. Identify and explain a short circuit.</p> <p>6.8.4. Apply Ohm's law to the solution of problems involving electric resistances connected in series, parallel, or combinations of the above.</p>	7
6.9	Electrical Energy and Power - Joule's Law.	<p>6.9.1. Apply the law of conservation of energy to conversions between electrical energy and other forms of energy.</p> <p>6.9.2. Formulate Joule's law.</p> <p>6.9.3. Define the terms electrical energy and electrical power and connect electrical energy and electrical power with electric current intensity and potential difference.</p>	2
6.10	Electromotive force. Internal resistance.	<p>6.10.1. Define the electromotive force (EMF) and the internal resistance of a potential difference source.</p> <p>6.10.2. Experimentally calculate the electromotive force and the internal resistance of a battery.</p>	2
6.11	Kirchhoff's rules for complex DC circuits.	<p>6.11.1. Understand Kirchhoff's laws and recognize that they derive from two fundamental laws of physics: The law of conservation of energy, and the law of conservation of charge.</p> <p>6.11.2. Identify that Kirchhoff's laws are useful in understanding the transfer of energy understanding the transfer of energy through an electric circuit, and that they are also valuable in analysing electric circuits.</p> <p>6.11.3. Apply Kirchhoff's laws in one or two-loop circuits.</p>	3
	Total		24

APPENDIX B: WORKSHEET EXAMPLE

A' Technical School of Limassol

Sch. Year : 2009-2010

Lab Worksheet in Physics #7

Date :

Lesson: Resistor Combinations

Teacher: Achillefs Kapartzianis

Name:.....

Class:

Group:

RESISTOR COMBINATIONS IN SERIES & IN PARALLEL**Prerequisite Knowledge:**

Resistor and Resistance. Current. Potential difference. Brightness.

Objectives :

Students to obtain the ability to:

1. Assemble simple electric circuits.
2. Identify and explain a short circuit.
3. Learn the basic concepts and relationships of current and potential difference in DC circuits containing resistors wired in series and parallel.
4. Learn the relationships of the total resistance of resistors connected in series and parallel.

Instruments and Materials :

1. Personal Computers running Edison 4 Demo
2. Pencils and Papers

Experimental Procedure

➤ Activity 1:

Which Circuits Work?

1. Look at the drawings on Prediction Sheet #1. Predict which bulbs in the drawings will light and which ones will not if we turn the switch on, and give reasons for your predictions.

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2. Share your ideas and explanations with your group members. Your group representative will present your group's ideas to the class.

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3. Open Edison 4 demo and test your predictions. Then decide if, based on your tests, you want to make any changes related to the electrical set-ups. What could be done to light the bulbs that did not light when you tried them? Test your ideas.

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4. Based on what you have seen in this activity, what statement or statements can you make about what is needed to light a bulb? What conditions are necessary for a circuit to be completed? What does "electrical short circuit" mean to you?

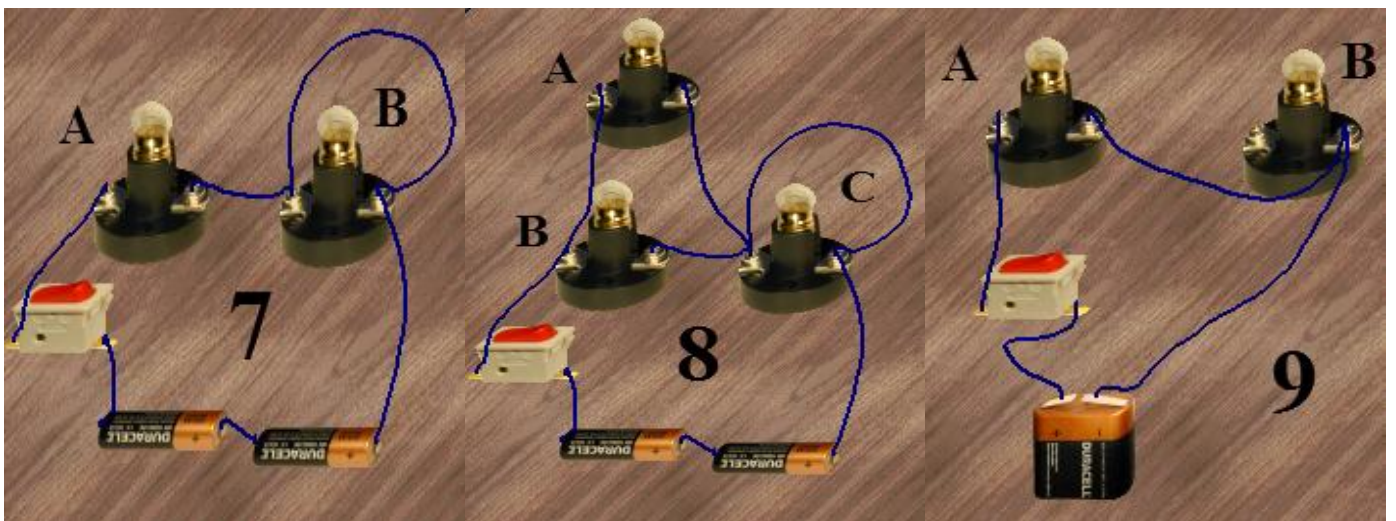
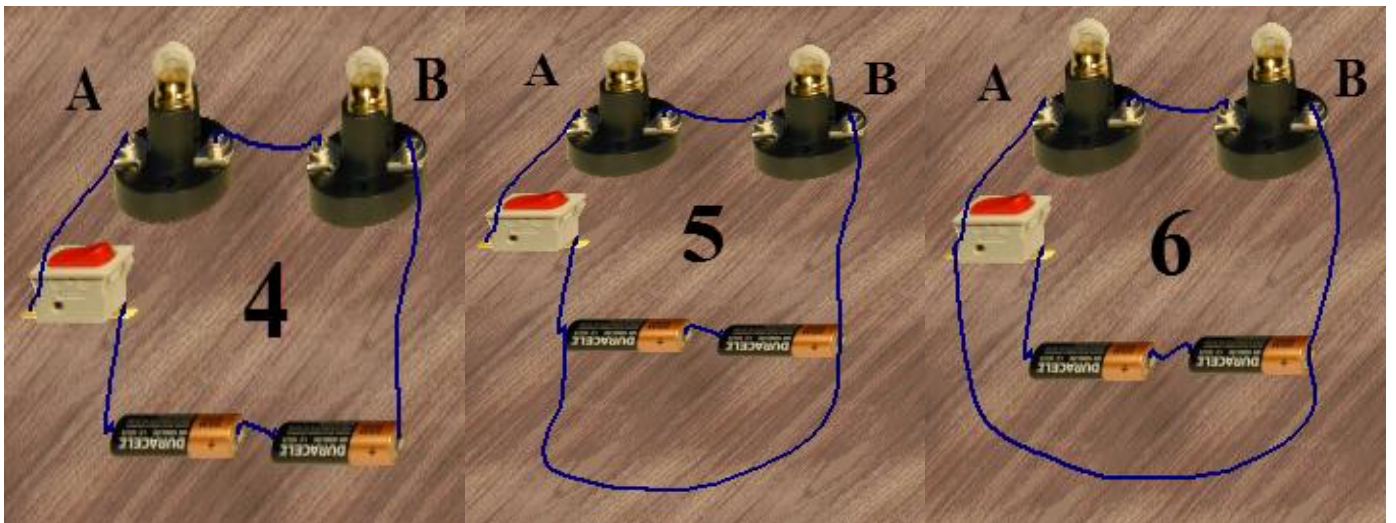
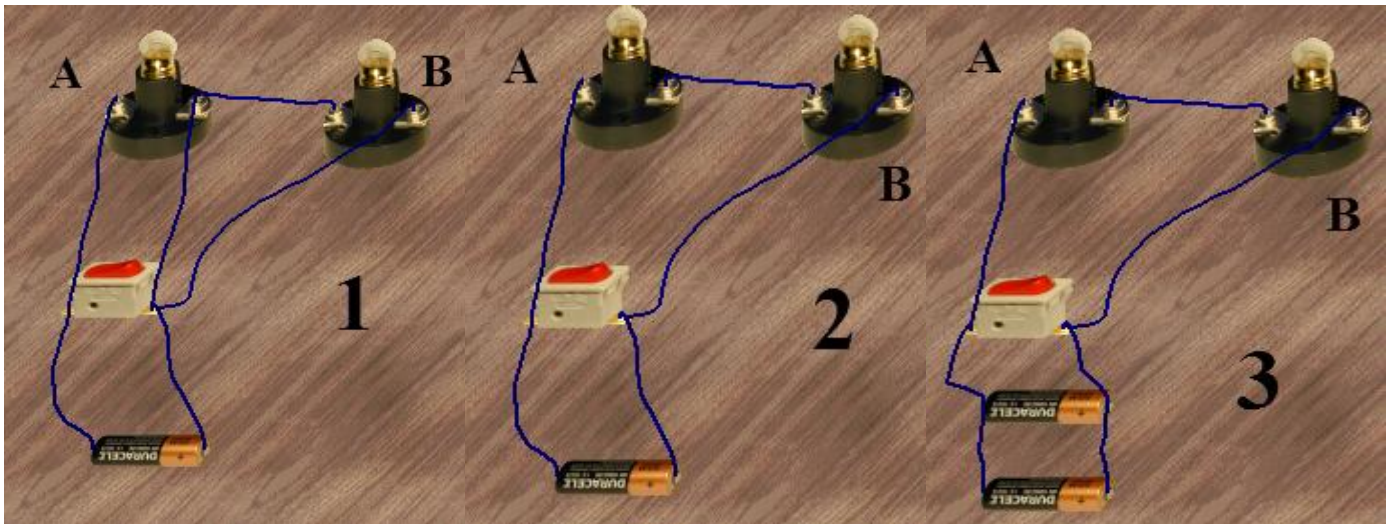
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5. Can you give examples of where we use electrical circuits? What would happen if in one of the situations where the light bulb did not light, we introduced another wire connecting one pole of the battery to the other? Where do electrical shorts occur in our daily lives? What are some of the things which may happen when there is an electrical short circuit?

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6. Between now and the next session, think of other examples, questions, or problems on the topic of complete circuits and electrical shorts, and bring them to class to share.

PREDICTION SHEET #1. Will the bulb(s) light?



➤ **Activity 2: Lighting Two Bulbs**

A. Constructing a Two-bulb Circuit

1. Using the least number of batteries and wires, make a drawing of set-ups that will light two light bulbs at the same time. Think of different ways to do this and draw them. Provide reasons for your drawings and explain if there will be a difference in the outcome with the different set-ups. If so why?

2. When you have a circuit that you believe will light the two bulbs, decide whether there will be a difference in the brightness of the bulbs and think a reason why.

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3. Share your drawings and explanations in your small group and have your representative present everyone's ideas to the large group. Be prepared to ask clarifying questions or answer questions from others.

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4. Get the necessary bulbs, batteries, and wires, and test your ideas by connecting them in different ways. Do you notice a difference in the brightness of the bulbs when they are connected in a different way?

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B. Which Two-bulb Circuits Will Work?

1. Look at the drawings on Prediction Sheet #2. Predict which of the bulbs in the drawings will light and which ones will not, and give reasons for your predictions. Also, in each case that you believe the bulbs will light, predict what will happen if one of the bulbs is unscrewed and removed from the set-up. Give reasons for your predictions.

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2. Share your ideas and explanations with your group members. Your group representative will present your group's ideas to the class.

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3. Open Edison 4 demo and test your ideas by setting up the circuits as on the prediction sheets. For the set-ups that you predicted would not light the bulbs, what you can do to make them light? Test your ideas.

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4. From what you have learned in the two parts of this activity, what statements can you make about electrical circuits that have more than one light bulb? Why is there a difference in the brightness of the bulbs when they are connected differently? What happens in each case to the brightness of the remaining bulb when you remove one bulb? Can you think of other analogies where this may be true? What do we call different kinds of circuits?

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5. Where do we use different circuits? What experiences have you had with in parallel and in series circuits?

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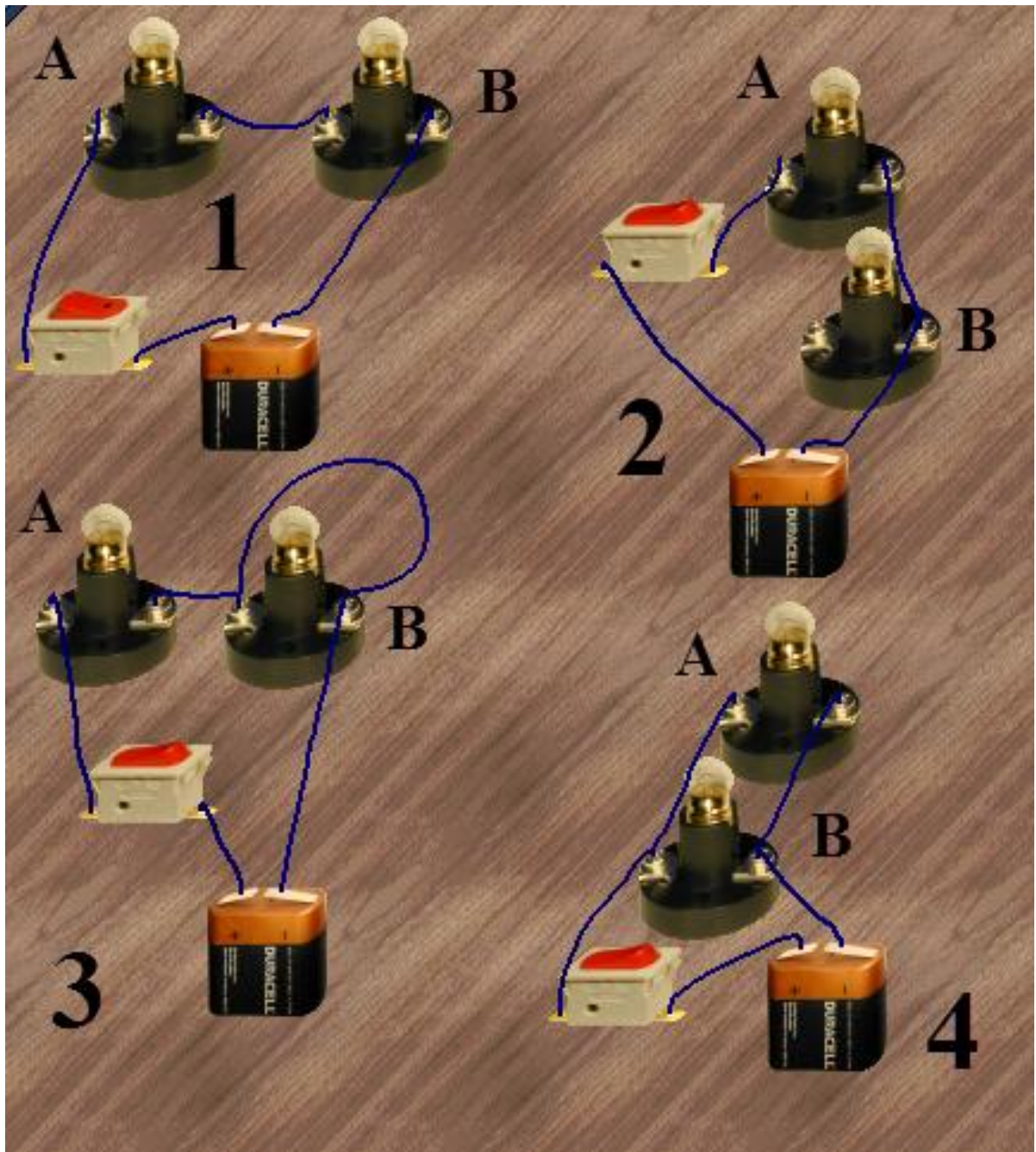
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6. For the next session, bring other examples, questions, and problems on electrical circuits that you may be interested in pursuing.

PREDICTION SHEET #2. Will the bulb(s) light?



APPENDIX C: ETHICAL CLEARANCE FORM

2 June, 2011

Mr. Achillefs Kapartzianis

Dear Mr, Achillefs,

REQUEST FOR ETHICAL CLEARANCE: Designing Conceptual Change Activities for Improving the Physics Curriculum: The Cyprus Paradigm

Your application for ethical clearance of the above study was considered by the ISTE sub-committee on behalf of the Unisa Research Ethics Review Committee on 20 January, 2011.

After careful consideration, your application is hereby **approved** and hence you can continue with the study at this stage.

Congratulations.

C E OCHONOGOR, PhD
CHAIR: ISTE SUB-COMMITTEE

cc. **PROF T S MALULEKE**
EXECUTIVE DIRECTOR: RESEARCH

PROF M N SLABBERT
CHAIR- UREC.



APPENDIX D: MEAN RATE PER CATEGORY OF POST PRE-TEST POST POST-TEST INTERVIEW QUESTIONS CCMBI

