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CONCEPTUAL CHANGE ACTIVITIES ALLEVIATING MISCONCEPTIONS ABOUT ELECTRIC CIRCUITS

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Abstract. *This study contributes to a growing literature that investigates vocational students' conceptual understanding of electricity by proposing a multidimensional and pragmatic approach to conceptual change. Conceptual change model-based activities were designed in a six-stage conceptual change model and were incorporated into a four-week course. The effectiveness of these activities was measured in terms of changing these students' misconceptions about simple electric circuits towards scientifically accepted ideas in terms of their revolutionary versus evolutionary nature and the extent of transfer of learning. Transformative mixed methods research design was used consisting mainly of a one-group pre-test post-test design with DIRECT Test 1.2 as a research instrument. Paired samples t-test analysis for 15 students' test scores indicated that there was a statistically significant difference between students' pre- and post-test scores. The results of the frequency analysis in both pre- and post-tests show a significant percentage drop in the number of students having the identified misconceptions. The majority of students during post pre-test interviews justified their answers incorrectly, but more than 80% answered correctly in the post post-test interview.*

Key words: *conceptual change, conceptual change model, electric circuits, misconceptions, vocational education.*

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Introduction

The most common students' misconceptions have been investigated and recorded in the thematic region of simple electric circuits. The following models have been reported on by the researchers indicated in brackets: the unipolar/sink model; the clashing current model; the weakening current model; the shared current model (Osborne & Freyberg, 1985; Koumaras et al., 1990; Driver et al., 1994; Borges & Gilbert, 1999; Koltsakis & Pierratos, 2006); the sequence model (Shipstone, 1984; Engelhardt & Beichner, 2004); the local reasoning model (Cohen, Eylon & Ganiel, 1983; Heller & Finley, 1992); the short circuit model (Shipstone, Jung & Dupin, 1988; Engelhardt & Beichner, 2004); the battery as current source (Heller & Finley, 1992; Borges & Gilbert, 1999); battery and resistive „Superposition principle"; term confusion and rule application error (Koumaras et al., 1990; Engelhardt & Beichner, 2004) and topology (Engelhardt & Beichner, 2004).

The results of these studies showed that pupils, high school students and even their teachers (Wiles & Wright 1997; Kock, Taconis, Bolhuis & Gravemeijer, 2013), as well as practitioners (Borges & Gilbert 1999) share a number of misconceptions about electricity. These misconceptions were repeatedly observed in various countries, among people from different cultures who had been through different educational systems (Duit & Von Rhoeneck, 1998; Taber, de Trafford & Quail 2006; Shipstone, Jung & Dupin, 1988).

Although the evidence about students' conceptions has been accumulated over the years, in the development of science curricula the challenge becomes choosing and combining these misconceptions about electricity concepts in such a way that they promote an understanding of theoretical concepts (Kock et al., 2013). Furthermore, there is an increased interest in the academic community to investigate vocational students' conceptual understanding of electricity and find the way to develop conceptual understanding among these students (De Jong, et al., 2013; Kollöffel & de Jong, 2013). Remedies have been suggested to overcome conceptual problems in electricity, but with limited success (Mullhall et al., 2001) and the topic is still receiving attention (Engelhardt & Beichner, 2004; Hart, 2008; Taber et al., 2006, Duit & Schechker, 2007).

Researchers (Posner, Strike, Hewson, & Gertzog, 1982; Stepans, 1994; Hake, 1998; Alonso-Tapia, 2002) claim that helping students develop and enhance their conceptual understanding requires a great deal of cognitive effort. The nature of the conceptual change process has been extended to encompass more than the sole view of Piaget's notion of accommodation, namely to be revolutionary or evolutionary. Revolutionary in this instance means that learners were observed to vacillate between new and old conceptions (Tao & Gunstone, 1999), while evolutionary relates to research on the transfer of learning across contexts (e.g. Schwartz, Varma & Martin, 2008). Learners therefore undergo near-transfer or far-transfer. Near-transfer relates to learners applying new conceptions to similar contexts in which learning occurs, while far-transfer relates to applying new conceptions to different contexts.

Theoretical Framework

The conceptual change model (CCM) was developed by Posner et al. at Cornell University in the early 1980s. They took the theory based on Piaget's ideas of *assimilation* and *accommodation* (1929, 1930), as well as Thomas Kuhn's description of scientific revolution (1970) and Irme Lakatos's notion of theoretical hard core ideas to formulate their model of learning (1970).

Since its inception, the CCM has been widely accepted and considered as influential, but has also been the subject of criticism. According to Tao and Gunstone (1999), this criticism is mainly levelled at its rational nature and 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 argue that a wide range of factors needs to be taken into account in conceptual change.

In the years that followed, other models of conceptual change were proposed (Champagne, Gunstone & Klopfer, 1985; Carey, 1991; Chinn & Brewer, 1993; Stepans, 1994). In addition, several researchers have focused on conceptual change processes in terms of mental models (e.g. Ioannides & Vosniadou, 2002; Linder, 1993). Of these conceptual change models, the researchers of the study reported on in this paper decided to implement the conceptual change model for instructional design, developed by Joseph I. Stepans. The reason is that this six-stage CCM is an activity-centred, constructivist teaching-and-learning strategy that places students in an environment which encourages them to identify and confront their own preconceptions and those of their classmates, and then work towards 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, Saigo & Ebert, 1999).

Based on Posner et al.'s theory, this model 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 previous research of several authors (Nussbaum & Novick, 1982; Posner et al., 1982; Clement, 1987; Driver & Scanlon, 1989; Stepans, 1988, 1991). As a result, in Stepans's 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 students' 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 students in their classroom.

Furthermore, Stepans's CCM is designed to foster active student collaboration within the classroom. Students communicate with one another and the teacher to find information and solutions to their questions and to discuss their findings and understandings. Through active collaboration, students also learn to value and respect one another's ideas. The results of many studies indicate that collaborative learning significantly influences learning outcomes and has been associated with gains in variables such 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).

Therefore, this model (see Table 1 (Stepans et al., 1999, p. 141)) provides the opportunity for students to vacillate between new and old conceptions as well as to apply new conceptions to similar and different contexts in which learning occurs.

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Table 1. Description of the CCM.

CCM	Description	Functional dimension of the stage
Stage 1 Commit to a position or outcome phase	Students become aware of their own preconceptions about a concept by responding to the questions, or by attempting to solve the problem or challenge.	The teacher asks the student questions or presents 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 to the problem or challenge. During this phase the teacher does not comment on students' responses.
Stage 2 Expose beliefs phase	Students in small groups share and discuss their ideas, predictions and reasoning with their classmates before they begin to test their ideas with activities.	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 and explain the reasons that led them to this decision if they wish to. During this phase the teacher also does not comment on students' responses, but may help students clarify their views using a variety of ways.
Stage 3 Confront beliefs phase	Students confront their existing ideas through collaborative experiences that challenge their preconceptions, by working with materials, collecting data and consulting resources.	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. In this phase the teacher provides technical assistance to students and answer clarification questions if requested. Students in most cases become dissatisfied with their existing ideas during this phase 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.
Stage 4 Accommodate the concept phase	Students accommodate a new view, concept or skill by summarizing, discussing, debating and incorporating new information.	Students whose ideas are close to scientifically acceptable ones explain their views to their classmates with the aid of the teacher. 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.
Stage 5 Extend the concept phase	Students apply and make connections between the new concept or skill and other situations and ideas.	Students apply their newly acquired knowledge and skills in different situations. These situations may be presented by the teacher, or their fellow classmates, or by themselves.
Stage 6 Go beyond phase	Students pose and pursue new questions, ideas and problems of their own.	Students seek additional situations where acquired concepts or skills may be put into practice. Students can accomplish this 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.

This multidimensional and pragmatic approach to the CCM provided a theoretical framework for the present work, guiding the development of the activities and our data analysis and interpretation. It is pragmatic because it allows for the use of a variety of instructional activities "such as analogy, modelling, discrepant events and inquiry activities" (She & Liao, 2010, p. 95). It also encourages the use of teaching strategies based on views of prior knowledge being both constructive and a hindrance to learning. It is multidimensional because it allows the opportunity for students to see phenomena in qualitatively different ways. Secondly, they can be involved in a conceptual change process of socialization into a domain so that different perspectives are regarded as useful in various contexts and this is regarded as a socio-cultural perspective. Finally, it allows them to increase the status of the scientific conception by enhancing its perceived fruitfulness, plausibility and intelligibility relative to the misconception (Hewson & Lemberger, 2000).

The Aim of the Study

The aim of this study was to design conceptual change activities in simple electric circuits and to measure their effectiveness at promoting vocational students' conceptual change in terms of their revolutionary versus evolutionary nature and the extent of transfer of learning.

Two research questions were formulated:

- Do the identified misconceptions change towards scientifically accepted ideas after the implementation of a four-week instructional unit taught using conceptual change model based instruction (CCMBI)?
- What is the effect of CCMBI activities on students' misconceptions about simple electric circuits?

Methodology of Research

Research Design

A transformative mixed methods design (Creswell, 2008) was followed. CCMBI activities were developed and planned to address the misconceptions of secondary technical and vocational education (STVE) students. These activities were incorporated into a 4-week course on electricity.

Sample of Research

The target population was the 218 second grade (11th grade level) students that had chosen to study advanced physics in the STVE schools of Cyprus during the school year 2009-2010 (Ministry of Education and Culture, 2011). 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 the issue, students from this school represented a typical example of Cypriot STVE students.

A specific sample of 15 second grade (11th grade level) students was selected because it was the only class in the school in which the researcher could teach the course he designed for this study at that specific period. The sample consisted of mechanical engineering and graphic arts students with specialization in interior decoration. These students were tested by using DIRECT before the commencement of the four-week, 24-period course on electricity, and again after 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 completion of the course. In order to ensure approximately equal representation, the interviewees were selected according to their performance in the pre-test and gender.

Instruments

Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT)

The diagnostic instrument, Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT) version 1.2, translated into Greek by the researcher, was used. DIRECT was developed by Paula Engelhardt and Robert Beichner, professors of North Carolina State University, to evaluate high school and university students' understanding in a variety of resistive DC circuit concepts (Engelhardt & Beichner, 2004).

DIRECT is a 29-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 component of scientific knowledge that is related to simple electric circuits. The questions of each unit attempt to elicit students' preconceptions, for each constituent component of scientific knowledge.

The instrument was constructed around a set of 11 instructional objectives about simple electric circuits, which involve a number of different aspects. These objectives are presented in Table 2.

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Table 2. 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 elements 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's 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 remains 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 on course completion. The order of appearance of the questions in each test as well as the order of appearance of the answers to each question was rearranged to prevent students from simply memorising the correct answers in each question.

Field notes

Field notes were taken during and after the classes. The researcher highlighted what he thought was important, such as individual and group activities, students' attitudes and behaviours. Any theories that might have developed while observing a student or a group of students were recorded as were general notes on what students were saying or doing during class time.

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 during the interview.

Interviews

Qualitative data were collected by using semi-structured interviews. The responses from the interviews were analysed and compared with the test data in order to draw more accurate inferences about the students under study. The interview questionnaire contained both fixed-alternative items and open-ended items.

The interview questions that were used were drawn from similar research done in Greece by Koumaras (1989) and its reliability and validity have been tested and the results published.

The interviewees were evenly selected from high, middle and low performing groups, and an effort was 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, 2008, p. 137). According to the progress made during the interviews, additional questions were also asked in some instances. Students were interviewed for between 30 and 40 minutes. All the interviews were recorded with the consent of students and transcribed.

Procedure: Development of Activities

Students need to actively construct their own knowledge and make decisions about changing their own conceptions (Duit & Treagust, 2003). They must also be able to apply new conceptions to similar and different contexts in which learning occurs. This view influenced the development of activities based on the CCM. Firstly, an analysis of the previous curriculum was done to ensure that all sections with regard to simple electric circuits were addressed. Secondly, the activities addressed the misconceptions that were found most frequently in previous research studies, as well as in our baseline research (Kapartzianis & Kriek, 2011). Some of the instructional activities were adopted from various sources (Koumaras, 1989; Sherwood & Chabay, 1999; Kapartzianis, Makris & Hadjicostis, 2008; Stepans, 2008; Testa, 2008; Garganourakis, 2009a, 2009b, 2009c, 2009d) and the remaining activities were developed by the researcher.

Instructional activities that include multiple representations of the concept add new layers of understanding for that concept and can bring it closer to the student. Furthermore, representability is essential for making difficult concepts more intelligible (Hewson & Thorley, 1989). Therefore, the teaching strategies that have been found to promote conceptual change are to use activities that include analogy, modelling, discrepant events and inquiry activities by using laboratory equipment, objects from everyday life, ICT tools such as PowerPoint slides and simulation software such as Edison 4 and Virtual Labs Electricity. In this way students are given the opportunity to see phenomena in qualitatively different ways.

The six stages of the CCM were used in the development of each activity. An activity would, for example, consist of actual circuits constructed prior to the lab session. Students would have to predict which bulbs in the drawings would light and which ones would not if the switch was turned on, and they had to give reasons for their predictions. They were asked to share their ideas and explanations with their group members. This was to commit each student to a position of the outcome phase (see CCM). One group representative presented their group's ideas to the class (*expose beliefs phase*). When this was done, they had to open Edison 4 demo and test their predictions individually. The teacher then circulated around the room, listened to and monitored discussions between group members, and provided technical assistance only when asked. He also answered questions of clarification if requested (*confront beliefs phase*).

Next, students were requested to answer questions given to them on the worksheets provided. These questions varied in cognitive level. This is part of the *accommodate the concept phase* and *extend the concept phase* in the CCM. They needed to submit the worksheets to the teacher before they left class. At home, students had to complete in their workbook other examples, questions and problems on electrical circuits that they may have been interested in pursuing to construct or discuss in the following lesson (*go beyond phase*).

The purpose of the questions and completion of the workbook was to provide information to the teacher on whether students' acts during the session made them change their minds about which circuits worked.

At home, the teacher studied students' responses to worksheet questions and noted the students' initial opinions about which circuits worked and how they were formed at the end of the session. The feedback the teacher received from the students helped him to organize the next session and, if necessary, to make amendments to the

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worksheet he intended to use, or to the content of the conversation between him and the students.

This multidimensional and pragmatic approach to the CCM guided the development of the activities.

Data Collection and Analysis

Quantitative and qualitative data were presented and analysed in terms of revolutionary versus evolutionary nature and the extent of transfer of learning. This was done to determine a) if the misconceptions of STVE students that were uncovered initially changed towards scientifically accepted ideas after the implementation of the four-week instructional unit taught using CCMBI and b) to measure the effectiveness of CCMBI activities regarding students' misconceptions about simple electric circuits.

The quantitative research consisted of a pre-experimental one-group pre-test post-test design with DIRECT 1.2 as a research instrument. CCMBI, the independent variable, was implemented to determine the effect on students' level of understanding of simple electric circuits. In the first stage of misconception data analysis obtained from the pre-test and post-test items, three categories of answers were created: a) correct answer, b) misconception and c) other (Paraskeyas & Alimisis, 2007). In the first category, the correct answers were classified according to the answer key given by DIRECT developers Engelhardt and Beichner. In the second category the answers that expressed students' alternative perceptions that contradicted scientific knowledge were classified. This category was later analysed as a second stage and divided into subcategories based on the specific misconception that corresponded to the answer that students gave. The third category contained the remainder of the answers that students gave and did not fall into either of the first two categories.

The qualitative research consisted of interviews and field notes which were taken by the researcher during the lessons and used for triangulation. The same five participants were interviewed after they had written their pre-test and their post-test. They were asked to answer 14 questions and their answers were recorded. The field notes analysis not only confirmed the validity of the data obtained from the tests and interviews, but also may have revealed possible factors contributing to the observed differences.

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 & Kocakülah, 2007). These categories are shown in Figure 1.

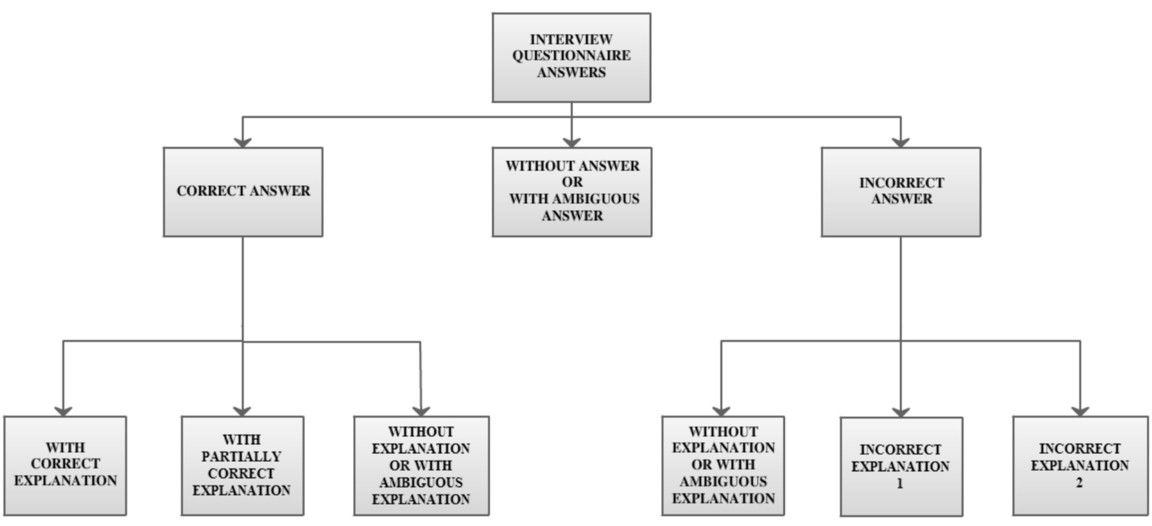

Figure 1: Analysis of Interview Questions.

In order to classify the students' answers, different levels under two categories were determined. These categories comprised the classification of similar explanations that fell into the same level. Apart from these levels, ambiguous answers or no answer constituted the other category. There was a discussion with a group of experienced teachers regarding the extent to which an explanation would be considered correct or partially correct, and also the level into which an explanation to an incorrect answer would 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: Responses involved correct answers in the fixed-alternative part of the question and also a scientifically accepted explanation in the open-ended part of the question.
b) With partially correct explanation: Responses involved 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.
c) Without explanation or with ambiguous explanation: Responses involved correct answers in the fixed-alternative part of the question, but with explanations in the open-ended part of the question whose meaning was difficult to understand, explanations that had no relation to the questions or no explanation at all.

Incorrect Answer Category

a) Without explanation or with ambiguous explanation: Responses involved incorrect answers in the fixed-alternative part of the question, with explanations in the open-ended part of the question whose meaning was difficult to understand. Explanations that had no relation to the questions or no explanation at all also fell into this level.
b) Incorrect explanation 1: Responses involved incorrect answers in the fixed-alternative part of the question, but with explanations in the open-ended part of the question focusing on the minority or majority of any circuit component and the way the circuit is connected.
c) Incorrect explanation 2: Responses involved incorrect answers in the fixed-alternative part of the question, but with explanations in the open-ended part of the question that could not be categorized in the two previous levels.

Without Answer or With Ambiguous Answer

No responses at all to the fixed-alternative part of the questions or answers that were given to the open-ended questions that were completely irrelevant were placed in this category.

Results of Research

Quantitative Results
Pre- and post-test scores

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 class average for the pre-test was 34.87% and for the post-test 62.52%.

Paired samples t-test

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

Table 3 contains the output of the paired samples t-test. The mean test scores before (pre-test) and after (post-test) were compared.

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Table 3. Pre- 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

The post-test mean scores were higher, which implies that student performance improved after implementation of the conceptual change-based activities.

Table 4 indicates the correlation between the two variables.

Table 4. Pre- and Post-test Paired Samples Correlations.

		N	Correlation	Sig.
Pair 1	Pre- & post-test	15	0.601	0.018

The correlation coefficient of 0.601 shows that 60% of the students that performed better than the other students on the pre-test also performed better than the others on the post-test.

Finally, in Table 5, the results of the paired samples t-test are presented. This test is based on the difference between the two variables. Under "Paired Differences" the descriptive statistics for the difference between the two variables are indicated. To the right of "Paired Differences", the t value, degree of freedom and significance are given.

Table 5. Pre- and Post-test Paired Samples T-test.

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Pre-test – post-test	-27.651	11.081	2.861	-33.788	-21.515	-9.665	14	0.000

The t-value is -9.665, the degree of freedom is 14 and the Sig. (2-tailed) is 0.000. The significance value indicates that there was a significant difference between pre- and post-test scores.

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. Table 6 presents the descriptive statistics for both groups.

Table 6. Pre- 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

The students' pre-test mean scores in both groups are almost the same and could be because of the careful selection of interviewees. The post-test mean scores of students that were interviewed were slightly higher.

The results of the post-test independent samples t-test are captured in Table 7. The results of this test indicate if there was a significant difference between the two groups' post-test scores.

The Levene's Test for Equality of Variances indicates whether the variability of each group is approximately equal. Under "T-test for Equality of Means" and starting from the left the t value, degree of freedom and significance are given.

Table 7. Post-test Independent Samples T-test.

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

The significance value of Levene's test is 0.795. 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, the degree of freedom is 13 and the Sig. (2-tailed) is 0.262.

The significance value implies that there was no significant difference between the post-test scores of the group of students that were interviewed and those that were not. Hence, from now on, it will be assumed that these two groups' achievement and misconceptions follow similar patterns and their results will not be discussed separately.

Students' Achievement

The students' achievement was checked in each of the instructional objectives that DIRECT examines and are analytically presented in Table 8.

Table 8. Objectives for DIRECT and test results.

Objectives		Question No	Average 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.	9, 18	40	83
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	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

Objectives		Question No	Average Percentage Correct	
			Pre-test	Post test
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

Students' Misconceptions Frequency Analysis Results

A frequency analysis of students' misconceptions in both pre-test and post-test was performed. The results are presented in Figure 2.

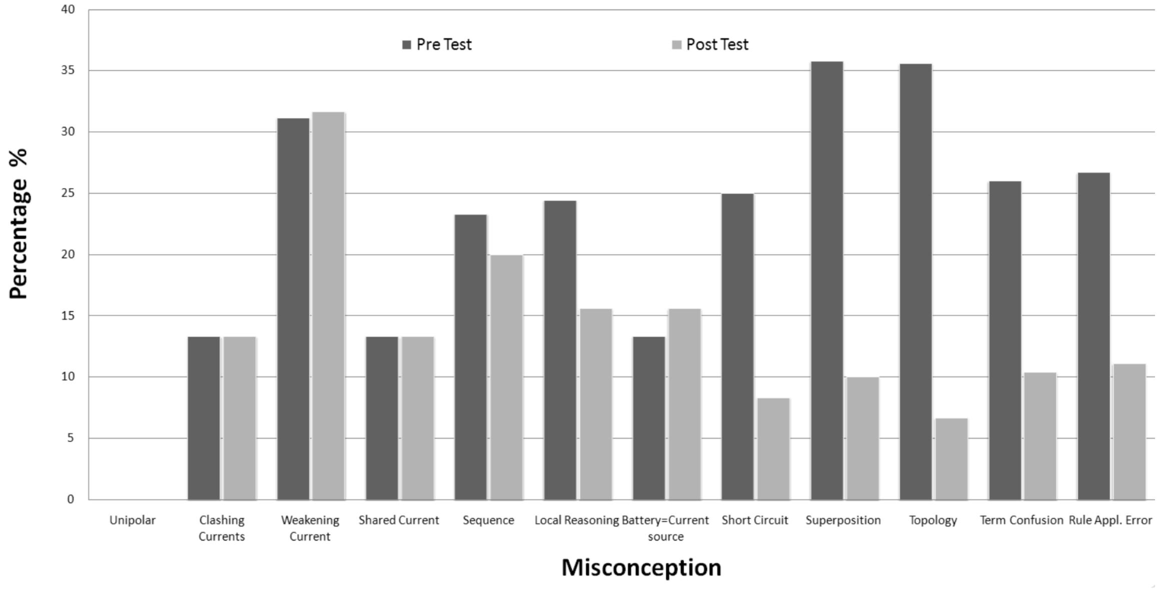

Figure 2: Rate of pre-test post-test misconceptions appearance.

In the analysis of the diagram, it is clear that a percentage of the students that adopted the *clashing currents* and the *shared current model* remained unaltered even after instruction.

Furthermore, instruction not only failed to decrease the percentage of students that adopted the *weakening current model*, but this percentage increased slightly in the post-test analysis.

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

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

The percentages of students that adopted the *short circuit, superposition* and *topology* dropped significantly after instruction. There was also a significant decrease in the percentage of students that *confused the terms* that occur in simple electric circuits or *misapplied a rule* governing circuits.

After consulting the test answer key supplied by Engelhardt and Beichner, the impact of CCMBI 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 taught using CCMBI.

Qualitative Results
Interviews

During the course of the interview session that followed the post-test, it was evident that considerable advances had been made in students' knowledge about the objectives DIRECT examines (see Table 8), which were taught using CCMBI. This is illustrated in Figure 3 below.

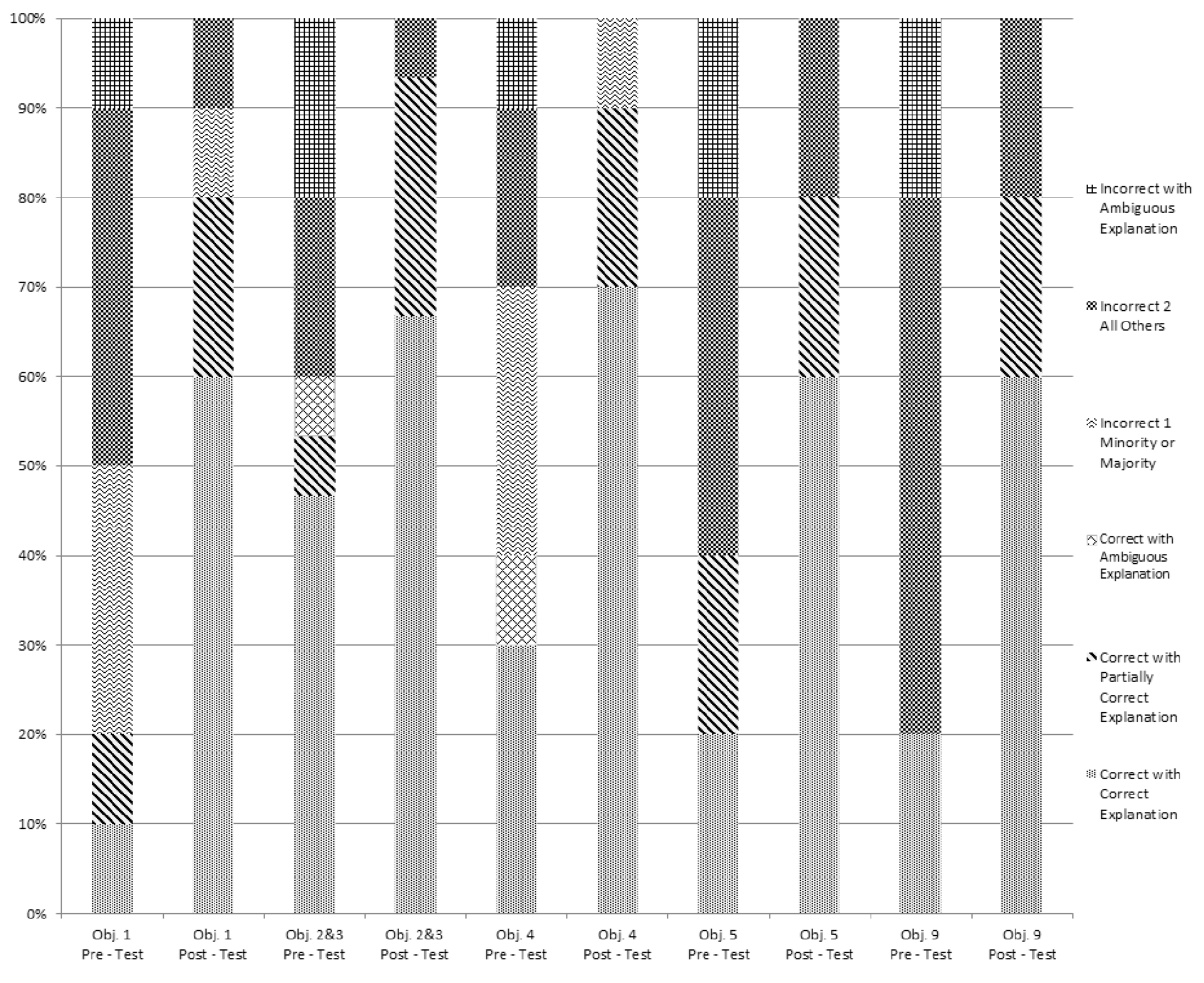

Figure 3: Mean rate per category of post pre-test post post-test interview questions CCMBI.

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Students' responses to these interview questions were classified according to statements reflecting students' misconceptions about simple electric circuits. The misconceptions that students revealed most often are represented by solid dots and the misconceptions revealed less often are represented by hollow dots, as suggested by Engelhardt and Beichner (2004). The results from this research are presented in Table 9.

Table 9. Misconceptions found during classification of incorrect answers to interview questions.

Misconception	Description	Post Pre-test Interview	Post Post- test Interview
Unipolar	Only one cable that connects the battery with the light bulb is needed in order to light the bulb	N/A	N/A
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	●	◯

Solid dots indicate misconceptions encountered most often. Hollow dots indicate misconceptions encountered less often.
●◉⦿◯○
0%≤ ○≤20%, 21%≤ ◯ ≤40%, 41%≤ ⦿ ≤60%, 61%≤ ◉ ≤80%, 81%≤ ● ≤100%

The results from the analysis of the post pre-test and post post-test interview data not only confirmed the results of the quantitative data analysis, but lead to interesting findings that we probably could not have obtained 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 CCMBI, this situation changed dramatically, as the majority of the interviewees defined electric current as "the rate at which electrons flow through a surface". This definition is in a more scientifically acceptable direction, but not scientifically correct, and may have been a result of our activities that relied on simulations where the moving particles were always electrons.
b) Although students were able to identify a short circuit after instruction, they did not understand its effects in most cases. So when students were asked to answer question 9 (Figure 4), the majority of their

answers were summarized as: "The battery in figure B will run down faster than the battery in figure A because in figure A there is no bulb to consume the current (or the energy) of the battery" (after pre-test). "The battery in figure B will run down faster than the battery in figure A because in figure A there is a short circuit so the energy will flow back to the battery" (after post-test).

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

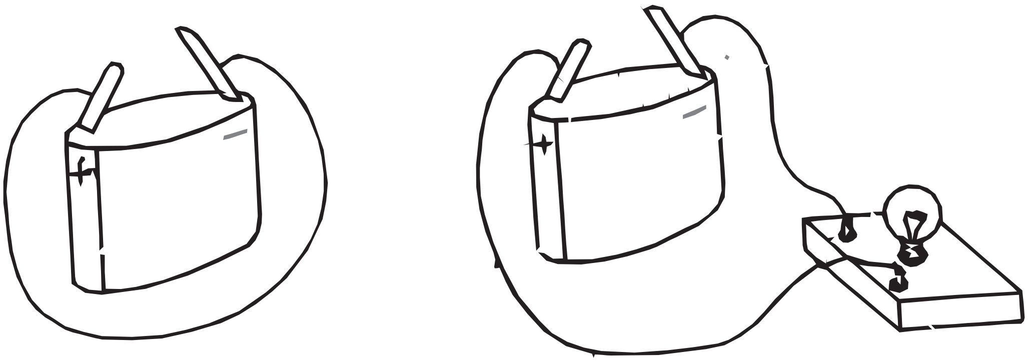

Figure A Figure B

Figure 4: Interview Question 9.

Field Notes

Example observations from the researcher's field notes showed that students' interest during lab activities rose after the completion of each class. During the first class in which students started working in groups, it was noticed that in each group of four students one or two students appeared to be very interested in performing the lab activities, one or two seemed semi-interested, and one student did not seem to be interested at all. This situation gradually changed. 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 observed 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 did not seem to pay attention to what the researcher was saying or doing, as they just had a set stare. Many times during in-class lectures when students were asked why they were not paying 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 did not seem to discourage them when performing lab activities.

Field notes analysis also showed that during CCMBI activities, students gradually developed a sense of collegiality with group members, cooperating in harmony, while some students assumed the role of "encourager" and helped other group members. In addition, 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 why he/she could not fulfil the task he/she was assigned to complete. If the explanation was not satisfactory, students asked the researcher to exclude this student from the overall group grading.

Moreover, students' significantly improved performance in the post-test DIRECT and interview questionnaire items that examined the concepts taught using CCMBI was perhaps due to the fact that during CCMBI students were expected to write scientific explanations by making a claim, supporting it with evidence and then explaining this claim to other group members and to the whole class using the related scientific concepts.

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Conclusions

A multidimensional and pragmatic approach to conceptual change was proposed that places students in an environment which encourages them to identify and confront their own preconceptions and those of their peers, and then work towards resolution and conceptual change. CCMBI activities were developed by including a variety of instructional activities to enhance understanding of the concepts to offer students the opportunity to see phenomena in different ways and enhance the concepts to perceive their fruitfulness, plausibility and intelligibility. The effectiveness of the activities was measured in terms of changing students' misconceptions about simple electric circuits towards scientifically accepted ideas in terms of their revolutionary versus evolutionary nature and the extent of transfer of learning. The identified misconceptions used in this study were those that have been repeatedly observed in various countries, among people from different cultures, and the theoretical framework guided the development of the activities through the use of Stepans's conceptual change model.

As the sample was very small, the results cannot be generalised and the researchers could not rely on quantitative analysis alone, so more data collection methods were used. The effectiveness of the activities was measured by using data obtained through 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 and post-test scores. After CCMBI implementation students became more successful in the instructional objectives that were taught using CCMBI, but there was no important change in students' success in the remainder of the instructional objectives that DIRECT examined (Table 8).

The results of the frequency analysis of students' misconceptions in both pre-test and post-test (Figure 2) showed a significant percentage drop in the number of students with the misconceptions targeted by CCMBI and a negligible to non-existent difference in the rest of the misconceptions. This could indicate that learners vacillated between new and old conceptions and were able to transfer new conceptions to similar contexts in which learning occurs as well as apply new conceptions to different contexts.

Results from the analysis of the post pre-test and post post-test interview data (Figure 3) showed a significant increase in 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 correctly answered the interview questions that examined the objectives taught using CCMBI (see Figure 3). In the second stage the answers were further categorized into subcategories based on the specific misconception that corresponded to the students' answers. 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 Figure 3). Analysis of post post-test interview data revealed that in some cases the activities did support students' misconceptions and this was also seen in the frequency analysis of the *weakening current model.* This will be taken into consideration during the redesign of these activities before incorporation into the new national Physics curriculum of Cyprus schools.

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.

Conceptual change is a complex process, and requires the proper environment and equipment. Therefore, classrooms and/or laboratories must be equipped with the necessary materials and computer equipment.

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

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