Conceptual Change through Cognitive Perturbation using Simulations in Electricity and Magnetism: a Case Study in Ambo University, Ethiopia

by

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submitted in accordance with the requirements for the degree of

Doctor of Philosophy in Mathematics, Science and Technology Education

in the subject

Physics Education

at the

University of South Africa

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November 2012

Declaration

Student number: **45451885**

I declare that **Conceptual Change through Cognitive Perturbation using Simulations in Electricity and Magnetism: a Case Study in Ambo University, Ethiopia** 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.

___________________ ___November 2012

SIGNATURE DATE

(BEKELE GASHE DEGA)

Abstract

The purpose of this study was to investigate physics undergraduate students' conceptual change in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI). Along with this, categorization of students' conceptions was done based on students' epistemological and ontological descriptions of these concepts. In addition, the effect of cognitive perturbation using physics interactive simulations (CPS) in relation to cognitive conflict using physics interactive simulations (CCS) was investigated.

A pragmatic mixed methods approach was used in a quasi-experimental design. Data were collected by using the modified Diagnostic Exam of Electricity and Magnetism (DEEM), focus group discussions (FGD) and concept maps (CM). Framework analysis was conducted separately on FGD and CM qualitative data to categorize students' conceptions while concentration analysis was used to categorize students' responses to the modified DEEM into three levels, during pre and post intervention. In the qualitative results, six categories of alternative conceptions (naive physics, lateral alternative conceptions, ontological alternative conceptions, Ohm's P-Primes/ P-Primes, mixed conceptions and loose ideas) and two categories of conceptual knowledge (hierarchical and relational) were identified. The alternative conceptions were less frequently and inconsistently revealed within and across the categories. It was concluded that the categories have common characteristics of diversified distribution of alternative conceptions and multiple alternative conceptions of specific concepts within and across the categories. Most of the categories found in pre intervention persisted in post intervention, but with a lesser percentage extensiveness of categories of alternative conceptions in the CPS than in the CCS class and more percentage extensiveness of categories of conceptual knowledge in the CPS than in the CCS class.

ANCOVA was separately conducted on the scores of 45 students on the modified DEEM and CM tests to compare the effectiveness of the CCS and CPS. The results showed a significant difference between the two classes of the post test scores on the DEEM test, $(1, 36) = 4.66$, $p=0.04$ and similarly, on the CM test, $(1, 31) = 8.33$, $p=0.007$. Consequently, it was concluded that there is a statistically significant difference between CPS and CCS in changing students' alternative conceptions towards scientific conceptions favoring CPS. To characterize and compare students' conceptual change of both treatment classes, Hake's average normalized gain <g> from pre to post scores (the modified DEEM and the CM) were analyzed. Finally, it is suggested that in abstract conceptual areas of EM, cognitive perturbation through interactive simulations is more effective than cognitive conflict through interactive simulations in facilitating conceptual change, and, thus, should guide classroom instruction in the area. Furthermore, recommendations are also suggested for guiding future research in this area.

Keywords: alternative conception; categories of alternative conceptions; concentration analysis; conceptual change; electric potential and energy; electricity and magnetism; electromagnetic induction; framework analysis; students' conception; conceptual knowledge; cognitive perturbation; cognitive conflict; simulation

Acknowledgements

At the outset, I would like to thank the Almighty God in the name of Jesus Christ for blessing and giving me the wisdom, endurance and time in order to complete my PhD study. Then, there are a number of people who supported me, in one way or another, during my study and therefore need to be acknowledged.

I would like to address special thanks to my supervisor, Prof Jeanne Kriek, for all her kindly helpful and continuous professional comments, suggestions and support from the very beginning to the end of my study. I genuinely appreciate her expertise and punctuality in guiding me throughout the process of my study. I feel privileged to have her as a supervisor.

My sincere gratitude goes to my co-supervisor, Dr Temesgen Fereja, for his generous professional comments and suggestions on each draft of my work. In addition, I am immensely grateful to his brotherly advice and encouragement which benefited me in my research.

I would like to extend my thanks to the Government of Ethiopia for rendering me sponsorship to pursue my study in this PhD program. My thanks also go to Ambo University for providing me material support which helped me as one of the inputs to my success.

I am also indebted to Dr Tadesse Boyossa for editing some parts of this thesis despite his tight schedule. In addition, I thank the physics teachers and the students at Ambo University whose cooperation helped me to accomplish the intervention according to the schedule set.

I would like to thank my wife Hirut Gudina and my three kids Nathnael, Abel and Saron for their understanding, encouragement and support that they never complained when the study kept me busy. Finally, I would also like to thank my family, as a whole, whose prayers and supports have helped me attain this goal.

Part of this thesis has been accepted in an accredited international journal

Dega, B.G., Kriek, J., & Mogese, T. F. (2012).Categorization of Alternative Conceptions in Electricity and Magnetism: the case of Ethiopian Undergraduate Students. *Research in Science Education,* DOI: 10.1007/s11165-012-9332-z

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List of Abbreviations

CCS	Cognitive conflict with simulations
C_d	Concentration deviation
C_f	Concentration factor
CM	Concept maps
CPS	Cognitive perturbation with simulations
CSEM	Conceptual Survey of Electricity and Magnetism
DEEM	Diagnostic Exam of Electricity and Magnetism
EM	Electricity and magnetism
emf	electromotive force
EMI	Electromagnetic induction
EPE	Electric potential and energy
FGD	Focus group discussion
n_c	number of correct response
P-Primes	Phenomenological Primitives
PhET	Physics Education Technology
S	Score

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Electricity and magnetism (EM) is an essential domain of physics that deals with electromagnetic interaction. This, in turn, is one of the four interactions in nature[1] and plays a central role in determining the structure of the natural world. This interaction is the strongest after nuclear interaction. In addition, it is long ranged like gravitational interaction and dominates the structure of both living and non living nature. For example, the nature of inter-molecular and inter-atomic structures of solids and liquids are described by the concepts of electricity and magnetism (Serway & Jeweet, 2002). Furthermore, the knowledge of electricity and magnetism are the foundations of most current and emergent technologies and are applied in the operation of various electronic devices, such as radios, televisions, electric motors, remote sensors, computers, high-energy particle accelerators and different electronic devices used in medicine (Chabay & Sherwood, 2006; Serwey & Jewwett, 2002).

Like mechanics, the concepts of electricity and magnetism are the fundamentals of physics. These concepts are prerequisites in the transition of students understanding from classical to advanced modern physics. In mechanics, students are introduced to motion of visible macroscopic objects, like balls, cars and airplanes. The important concepts in mechanics, such as velocity and force, are easily related to their everyday experiences. As a result, students' conceptions in concepts of mechanics could exhibit a certain degree of coherence. However, the concepts in EM are significantly more difficult to understand than those in mechanics (Chabay & Sherwood, 2006). In line with this, the research conducted by Planinic (2006) showed that student' difficulties of most EM concepts remain the same; before and after instruction. A possible reason could be because students encounter motion of invisible microscopic objects, such as electrons; and abstract concepts, such as field, flux and potential, which are far beyond what they have experienced in mechanics. Hence, conceptual change approaches that have been

[1] The four interactions in nature are gravitational, electromagnetic, weak-nuclear and strong-nuclear.

used to change students' alternative conceptions in mechanics are believed inadequate for enhancing conceptual change in the abstract concepts of electricity and magnetism.

For the last three decades, the term conceptual change has existed in the literature of science education with regard to changing students' alternative conceptions of science concepts and phenomena. Most of these concepts studied during this era are those related to students' daily experiences, like the concept of force and motion in classical mechanics in which students alternative conceptions exhibit a certain degree of coherence. Moreover, the classical conceptual change model adopted the Piaget's developmental cognitive approach to discern differences in students' conceptions based on the epistemological perspective (Nussbaum & Novick, 1982; Posner, Strike, Hewson & Gertzog, 1982). Hence, in this model, students' learning of science concepts is perceived as a process of changing coherent students' conceptions to the intended scientific conceptions.

Current reviews of progress of conceptual change research shows that there are two prominent but competing theoretical perspectives regarding structure of students' alternative conceptions (Özdemir &Clark, 2007). These are alternative conception as a theory perspective (e.g., Chi, 2005; Ioannides & Vosniadou, 2002; Wellman & Gelman, 1992) and alternative conception as elements perspective (e.g., Clark, 2006; diSessa, Gillespie, & Esterly, 2004; Harrison, Grayson, & Treagust, 1999). These two theoretical perspectives imply different pathways for conceptual change to help students restructure their understanding (Özdemir &Clark, 2007). Earlier research literature has predominantly supported alternative conception as a theory perspective and consequently hypothesized revolutionary conceptual change through various strategies (Ioannides & Vosniadou, 2002; Linder, 1993; Vosniadou & Brewer, 1992). Consequently, different types of the classical conceptual change strategies have been distinguished during the last three decades. Cognitive conflict is one of the strategies in the classical conceptual change model (Hewson & Hewson, 1984; Posner et al., 1982) which has been mostly implemented in the learning of science concepts. This strategy is a dominant learning strategy making learners dissatisfied with their existing alternative conceptions and rendering the scientific conceptions intelligible, plausible and fruitful (Hewson & Thorley, 1989).

Alternative conception as a theory perspective has developed in different domains of science, such as force and motion (McCloskey, 1983), astronomy (Vosniadou & Brewer, 1992) and heat and temperature (Wiser & Carey, 1983). They all emphasize that learners at any given time maintain developed coherent alternative conceptions based on their everyday experiences, and that these alternative conceptions have explanatory power to make consistent predictions and explanations across domains of science.

However, currently, there are instructional propositions that potentially favor the adoption of alternative conception as elements perspective and hypothesize that the structure of students' alternative conceptions consists of multiple conceptual elements at various stages of development and sophistication (Özdemir &Clark, 2007). In addition, a growing number of studies (Li, 2011; Li, Law & Lui, 2006; Tao & Gunstone, 1999) indicate that students' learning of concepts in science is rather complex and idiosyncratic. From this perspective, conceptual change involves a gradually evolutionary process rather than a broad theory replacement process (Li, 2011; Li et al., 2006). The cognitive perturbation strategy involves step by step learning of concepts based on the understanding that paths of conceptual change for different students/groups of students are idiosyncratic, diverse and context sensitive (Li et al., 2006), but the cognitive conflict strategy is a one step and revolutionary process of conceptual change (Hewson & Hewson, 1984; Nussbaum & Novice, 1982; Tao & Gunstone 1999).

The concepts in electricity and magnetism are invisible and unfamiliar to students' daily experiences. It is believed that the use of appropriate interactive physics simulations available for teaching EM concepts is important to simplify the complex and invisible nature of these concepts, because they are designed to be interactive, engaging, and also to make explicit certain visual representations (Rutten, van Joolingen & van der Veen, 2012; Urban-Woldron, 2009; Wieman et al., 2008b). Furthermore, computer simulations are used to provide discrepant events in conceptual learning since they have the capacity to provide learners with an exploratory learning environment (Zacharia & Anderson, 2003). Therefore, interactive physics computer simulations of selected conceptual areas of the concepts are used as part of the supportive learning strategies because of the complex and invisible phenomena in electricity and magnetism.

Thus, although there is not yet a consensus on the structure of students' alternative conceptions and the strategies of conceptual change, it is important to examine an effective conceptual change strategy that may enhance students' learning of concepts in EM in which motion of microscopic objects, complex and difficult concepts exist. Hence, this study is mainly aimed at comparing the effectiveness of an emerging strategy from the evolutionary perspective of conceptual change with the dominant classical conceptual change strategy from the revolutionary perspective of conceptual change, to enhance learning of students in the concepts of EM. In other words, this research intends to study students' conceptual change in EM through cognitive perturbation using simulations (CPS) in relation to cognitive conflict using simulations (CCS).

1.2 Statement of the Problem

First Phase: Categorization of Students' Conceptions

Students' conceptions of physics concepts have been studied extensively in mechanics (McDermott & Redish, 1999; Minstrell, 1982; Ramadas et al., 1996) and DC circuits in electricity (Baser, 2006; Baser & Durmus, 2010; Bilal & Erol, 2009; McDermott & Redish, 1999; Rosenthal & Henderson, 2006). However, students' conceptions of the concepts in EM have not been investigated in great detail as in mechanics (Duit, 2009; McDermott & Redish, 1999; Planinic, 2006; Saglam & Millar, 2006; Soto-Lombana, Otero & Sanjosé, 2005). The investigations in the concepts of EM have mainly focused on the development and evaluation of diagnostic tests (Ding et al., 2006; Engelhadt & Beichner, 2004; Maloney et al., 2001; Marx, 1998; Saglam & Millar, 2004). The diagnostic tests are mostly multiple-choice items which are meant to identify students' conceptions in terms of the provided options only (alternatives). Normally, these options have one correct answer (the scientific conception) and three to four alternative conceptions.

However, the current view of identifying students' alternative conceptions is changing towards the emerging view of knowledge structures and categorization of conceptions because of the complexities of students' conceptions in the microscopic world of physics (Özdemir &Clark, 2007; Rebello, Zollman, Allbaugh, Engelhardt, Gray, Hrepic, et al., 2005). Consequently, the sole identification of students' alternative conceptions in a domain of science, as studied for the last 30 years, is inadequate for the design of appropriate supportive approaches and curricula in abstract and complex concepts, like electricity and magnetism. This inadequacy puts science/physics teachers in a difficult position. This is due to the fact that students' alternative conceptions in science are idiosyncratic and they have characteristics of vacillating from one context to another (Tao & Gunstone 1999; Li, 2011; Li et al., 2006). Moreover, the inadequacy of the sole identification of alternative conceptions is due to different perspectives, like "coherence versus fragmentation", on the structure of students' alternative conceptions (Chi, 2008; diSessa et al., 2004; Ioannides & Vosniadou, 2002). Previous studies on the structure of students' alternative conceptions have been conducted in the context of classical introductory mechanics, especially in relation to concepts of force and motion (Clark, D'Angelo, & Schleigh, 2011; diSessa, et al., 2004; Elby, 2010).

Earlier studies in the concepts of physics mostly used an epistemological perspective of conceptual change (Posner et al., 1982) to identify and change alternative conceptions of students. There are also other concepts where experts' *process* views are incommensurate with students' *material* conceptions (Chi, 2008; Chi & Slotta, 1993) which lead to the change of students' ontological perspective (see Section 2.3.1). In addition, it is believed that the categorization of students' conceptions makes clear some characteristic features of these categories, like the extensiveness of the categories and consistency/inconsistency of alternative conceptions in and across the categories. These characteristics are believed to be essential for the study of students' prior knowledge states, which are crucial in enhancing their learning towards scientific conceptions. However, so far, no study has been undertaken to categorize students' conceptions in the conceptual areas of EM based on students' epistemological descriptions and ontological considerations of concepts. In other words, knowledge about categories of students' conceptions that are anchored in students' own personal epistemological and ontological views in the concepts of electricity and magnetism is lacking (see Sections 1.6 & 1.10). Therefore, it may be important to conduct research on categorization of students' conceptions in EM in order to help them learn and succeed in physics. Hence, the first phase of this conceptual change investigation includes the identification of categories of students' conceptions on the basis of their epistemological and ontological views of the concepts in electric potential and energy (EPE) and electromagnetic induction (EMI) (see paragraph 3 in Section 1.6).

Second Phase: Comparison of Cognitive Conflict using Simulations and Cognitive Perturbation using Simulations

Students already face most of the EM concepts in school learning in the context where teachers mostly use the traditional transmission model and in this case Ethiopia is no exception. The traditional transmission model is ineffective in physics concepts learning (Dykstra, Boyle & Monach, 1992; Grayson, 1994; Hake, 1998). Consequently, students' alternative conceptions in EM often remain unstable and inconsistent after instruction. The concepts in EM are complex and involve abstract relations (Chabay & Sherwood, 2006) and can, therefore, be particularly problematic in students' learning. Moreover, studies on the assessment of difficulties in the concepts of EM have shown that the difficulties have similar trends across countries and universities (Maloney et al., 2001; Planinic, 2006; Saglam & Millar, 2006). Some studies (e.g., Finkelstein, 2005; Planinic, 2006) have reported several students scoring low results in conceptual diagnostic tests. For example, advanced level undergraduate physics students who scored good grades in EM were reported to lack understanding of basic concepts in EM, as they failed to answer more than one-half of the questions on the basic conceptual survey of electricity and magnetism (Finkelstein, 2005; Pepper et al., 2010). Along with this, studies reporting on students' concepts in EM at university level showed that the sequential structure of instruction which spends most of the course on problem solving was ineffective to reduce students' alternative conceptions (Chabay & Sherwood, 2006; Saglam & Millar, 2006; Planinic, 2006).

Conceptual change research has been conducted mostly in the context of developed countries with less emphasis at university level than in schools (Soto-Lombana, Otero & Sanjosé, 2005). In line with this, few studies have been conducted on how to address the conceptual difficulties of EM in the context of developing countries. Consequently, little is known about conceptual change research and learning in the context of Ethiopia, because no study has been conducted in relation to EM conceptual change. The Ethiopian National Curriculum for the BSc program in physics (Ministry of Education, 2009) does not give emphasis to students' conceptions and conceptual change learning. In other words, the learning of physics across universities in the country has not yet exercised the conceptual change approaches of learning. Therefore, a study of the students' conceptual change in electricity and magnetism concepts at the introductory undergraduate level is important; otherwise, the alternative conceptions may ultimately affect students' understanding of successive advanced physics concepts.

Different strategies have been introduced, of which cognitive conflict strategy of the classical conceptual change model has been used extensively (Dreyfus et al., 1990; Hewson & Hewson, 1984; Nussbaum & Novice, 1982). The cognitive conflict has been proposed and viewed as a revolutionary process of conceptual change of students with coherent alternative conceptions (Nussbaum & Novice, 1982; Tao & Gunstone 1999). However, if students have a minimal level of conceptual knowledge and inconsistent alternative conceptions in the concepts of EM, then cognitive conflict may not help students to change their alternative conceptions, because of the inconsistency of students' conceptions and the wide cognitive gap that exists between their prior conception and the scientific conception. Such remoteness of perceptions may create frustration in physics students who have little confidence in their conceptual knowledge of concepts in EM. The success of cognitive conflict approach depends strongly on the ability of each individual student to recognize and resolve this conflict (Limon, 2001). This means that several intellectually less able students may fail to recognize the conflict and some of those who do recognize it may not be able to resolve it (Planinic et al., 2005). In addition, students are often reluctant or unwilling to abandon their alternative conceptions formed upon their own experience (Chan et al., 1997; Planinic et al., 2005). Consequently, students may hold on to inconsistencies in a superficial way rather than undergo more radical change implied by the classical conceptual change theory (Lee & Byun, 2012; Zohar & Aharon-Kravetsky, 2005).

As discussed in paragraph 6 in Section 1.1, the fundamental idea of cognitive perturbation is based on the understanding that paths of conceptual change for different students/groups of students are idiosyncratic, diverse and context sensitive which involves a gradually evolutionary process rather than a broad theory replacement process (Li, 2011; Li et al., 2006). The types of perturbations necessary for initiating conceptual change would be determined by contexts in which students engage.

In addition, it is believed that the two competing strategies in this study, the cognitive conflict and cognitive perturbation, together with appropriate interactive physics simulations for teaching EM concepts may enhance conceptual change in a manner where their effects are investigated. As discussed in paragraph 7 in Section 1.1, simulations are useful in concept learning for visualization because of the complex and invisible nature of concepts (Rutten et al., 2012), the construction of knowledge through less guided exploration (Urban-Woldron, 2009) and the provision of discrepant events in exploratory learning environments (Zacharia & Anderson, 2003). Therefore, a study is needed on the effectiveness of cognitive perturbation using simulations in relation to cognitive conflict using simulations to contribute knowledge to the theory of conceptual change in science learning.

1.3 Aim of the Study

This study aims to investigate undergraduate physics students' conceptual change in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI). It encompasses two phases, the first identifies the categories of students' conceptions in the concepts of EPE and EMI, and the second studies the impact of cognitive perturbation through physics interactive simulations (CPS) in relation to cognitive conflict through physics interactive simulations (CCS). To this end, the objectives of this study are:

1. to identify categories of students' conceptions before intervention;
2. to identify categories of students' conceptions after intervention;
3. to compare effectiveness of conceptual change through cognitive perturbation using simulations (CPS) and conceptual change through cognitive conflict using simulations (CCS) in the concept of electric potential and energy (EPE) and electromagnetic induction (EMI).

1.4 Research Questions

The research questions of this study, corresponding to the objectives outlined above, are:

1. What are the categories of students' conceptions in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) before intervention?

2. What are the categories of students' conceptions in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) after intervention?
3. How significant is conceptual change through cognitive perturbation using simulations (CPS) as compared to cognitive conflict using simulations (CCS) in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI)?

1.5 Significance of the Study

This study extends the knowledge base of students' conceptions and conceptual change in the field of electricity and magnetism by means of analyzing the categories of students' conceptions and designing an appropriate supportive approach for conceptual change. The utility of categorization of students' conceptions is mainly to choose an appropriate approach for conceptual change, because the current prevalent knowledge of simply identifying alternative conceptions is inadequate for designing conceptual change approaches of learning, especially in the unfamiliar abstract and invisible concepts of electricity and magnetism.

This study also extends the knowledge of conceptual change learning within the domain of electricity and magnetism. In other words, this study extends the knowledge base from the prevalent classical conceptual change (cognitive conflict strategy) to the emerging cognitive perturbation strategy in undergraduate students' learning of the concepts in EM. The incorporation of suitable interactive physics simulations with learning strategies may be useful to develop insight into their effectiveness in enhancing conceptual change. Therefore, based on the above mentioned points, the physics education research community may benefit from the categorization of students' conceptions and the cognitive perturbation strategy through interactive simulations used to address conceptual change.

In addition, in the context of Ethiopia, most students who are majoring in physics become teachers in secondary schools after completion of their university study. Consequently, addressing these prospective teachers' alternative conceptions by using an effective conceptual change strategy is believed to positively influence their teaching in high schools. Physics curriculum experts may also benefit when designing and/or modifying the curriculum by giving emphasis to concepts learning in physics. Also, teacher education colleges across the country may use the results of this study to enhance teachers' professional development in relation to concept learning. Moreover, the strategies designed and results obtained in this study are believed to be used as input for school science teachers and university physics instructors in developing and formulating syllabi that can promote conceptual change.

1.6 Delimitation of the Study

Conceptual change research has different theoretical perspectives, such as epistemological, ontological and affective (Treagust & Duit, 2008). In the epistemological view, conceptual change is examined based on students' descriptions (different representations) of concepts being investigated (Duit & Treagust, 2003). In the ontological view, conceptual change is studied based on how students view the nature of a concept being investigated (Chi, 2008). In other words, it examines the ways the students consider concepts in terms of their views of reality, namely, as a material (substance) or a process. From the affective perspective of conceptual change, students' interests or motivations are examined on a concept or a subject being investigated (Pintrich, Marx & Boyle, 1993). Though motivational factors are important in concept learning, the students' motivations are not explicitly examined in this study. In other words, this study is delimited to epistemological and ontological perspectives of conceptual change.

The course on electricity and magnetism is outlined into 11 chapters according to the Ethiopian Harmonized National Curriculum for the BSc degree program in Physics (Ministry of Education, 2009). These chapters have different difficulty levels. The difficulties of comparable conceptual contents of EM were assessed by Planinic (2006) in the context of American and Croatian students. As a result, he categorized the concepts of EM into six broad conceptual areas with different difficulty levels by maintaining conceptual coherence of the concepts. These are electric charge and force, electric field and force, electric potential and energy, magnetic field and force, electromagnetic induction and Newton's laws in electromagnetic context.

This study is delimited to two of the aforementioned conceptual areas, the electric potential and energy (EPE) and the electromagnetic induction (EMI), for the following three reasons. Firstly, the conceptual areas are the most difficult parts of the EM concepts and challenge students across different countries (Planinic, 2006; Saglam & Millar, 2006). Secondly, students' alternative conceptions in these conceptual areas are so far not well addressed using appropriate supportive approaches that can lead to conceptual change. This is mainly because of the fact that alternative conceptions in these areas have not been thoroughly studied and documented compared to that of classical mechanics and DC circuits. Thirdly, there are recommendations (Chabay & Sherwood, 2006; Ding, Chabay, Sheewood, & Beichner, 2006; Maloney et al., 2001; Planinic, 2006) for the need to undertake in-depth studies by taking a few conceptual areas of EM using multi methods. Therefore, the findings from this study are delimited to the conceptual change process in the concepts of EPE and EMI and may not be generalized to other physics concepts.

1.7 Limitations of the Study

There are some conditions beyond the researcher's control that slightly affected the results and interpretations of this study. The first one is the inherent limitation of a case study. As a case study, the available sample size was used and therefore the results cannot be generalized beyond the specific situation from which the sample is drawn. The other limitation of this study is that some of the students who were available in the pre intervention data collection became unavailable or unwilling to participate in the post intervention data collection due to the length of the study. Moreover, there were few absentees during the intervention that could affect the result of the study.

1.8 The Research Context

According to the 2007 national census, Ethiopia is one of the most populous countries in Africa with a population of about 74 million (Central Statistical Agency [Ethiopia] & ICF International, 2012). This country developed a new Education and Training Policy in 1994. According to the Policy (Federal Democratic Government of Ethiopia, 1994), the Educational System of Ethiopia comprises the following categories:

1. Kindergarten (4 to 6 years) focuses on all round development of the child in preparation for formal schooling.

2. Primary education (7 to 14 years) is of eight years duration, offering basic and general primary education to prepare students for further general education and training.
3. Secondary education is of four years duration, consisting of :
    a. The first cycle of secondary education (two years) which enables students to identify their interests for further education, for specific vocational and technical training and for the world of work. This cycle of general education is completed at grade 10.
    b. The second cycle of secondary education and training (preparatory school) enables students to choose subjects or areas of training (natural sciences or social sciences) which prepare them adequately for higher education and for the world of work.
4. Higher education at undergraduate and graduate levels, is intended to be research oriented, enabling students to become problem-solving professional leaders in their fields of study and in overall societal needs.

The Educational System in Ethiopia is decentralized for the first three levels mentioned above, from kindergarten to secondary education. These levels are administered by the Regional Educational Bureaus through Zonal and Wereda (District) Educational Offices.

Higher education is centrally administered by the Federal Ministry of Education. This centralized system of higher educational administration has an impact on curriculum development and improvement. Along with this, the Higher Education Proclamation No. 650/2009 (Federal Democratic Government of Ethiopia, 2009) paragraph 21 number 4 states that

> Curricula common to any number of public institutions may be developed jointly through the participation of the public institutions responsible for their implementation; and such curricula shall serve as the minimum requirements applicable to any of the institutions.

On the basis of this proclamation, harmonizing curricula of public universities started in 2009. At the beginning, most of the natural sciences curricula were harmonized and implemented. Along with this, the New Harmonized National Curriculum for Undergraduate Physics was designed and has been implemented.

This study focuses on the undergraduate level of physics in higher education. In the National Curriculum for Undergraduate Physics, the courses descriptions (or contents of courses) and the recommended books for the courses are similar to those of most international universities. In addition, the modes of course delivery (methods of teaching) meant for the courses, including the course electricity and magnetism are mostly lecture based, physical and mathematical problem-solving and demonstration. However, ways of treating students' alternative conceptions and conceptual change strategies are not mentioned in the Physics Curriculum.

In Ethiopia, the concepts of EM are taught from junior secondary school to university. In school, they are incorporated in the subject general physics and are taught in grades 8, 10 and 12. At university level, EM is an independent course usually offered in the first year to physics and other sciences and engineering undergraduate students.

Currently, Ethiopia has 22 fully functioning and about 10 newly developing public universities. Students enroll in higher institutions after successful completion of two years of preparatory school education (grades 11 and 12). The enrollment criteria to all the universities of the country, Ambo University being one of them, are the same, and done nationally by the Federal Ministry of Education based on the students' choices, their academic performances and the programs offered at the universities.

In the universities, students can select programs (fields of study) of their interest based on their preparatory schools backgrounds. Students entering the universities have either natural or social science backgrounds from preparatory schools. Students who are allowed to join the department of physics are those from the natural science stream of the preparatory school. The universities use Higher Education Admission Scores (HEAS) as a criterion for competing and assigning them to programs.

Students from the natural science stream mostly want to study engineering, medicine and other health related fields as their first choice. Their second choice is non-physics related programs like, biology and chemistry. Currently, students have no interest to study physics at university level because of limited job opportunities in the industrial sector (Semela, 2010). In addition, the research conducted by Semela (2010) showed that students who have higher physics achievement in preparatory school and strong academic background do not want to join physics because the only job opportunity available for graduates is a teaching career.

In Ethiopia, a new strategic plan that stresses the importance of science and technology has been in place since the beginning of 2008 (Ministry of Education, 2008). According to this plan, universities are expected to enroll 70% of their students in science and technology and 30 % of their students in social science and business. Therefore, most students are being assigned to the department of physics without a choice. One of the reasons that the students raise for not choosing physics as their field of study is the difficult nature of the subject. That is, "physics is too abstract and theoretical such that one cannot see the application in the day to day life" (Semela, 2010, p 331). Moreover, some students attempt to compare their future benefits after graduation from university. They believe that fields, like engineering, medicine and other health related fields can benefit them more than physics after graduation because they imagine that they can easily form their own businesses with the knowledge and skills of the former fields rather than the latter.

Accordingly, most high scoring students wish to join study fields of their first and second choices, while less scoring students are forced to study physics. The enforcement is mainly due to the current higher demand for physics teachers than other science teachers in schools in the country. The other reason for the enforcement is the government plan to attain a 70:30 percent enrolment of new students into the public universities (Ministry of Education, 2008). Hence, the students who join the physics department to major in physics have little interest in the field and are unsuccessful in the competition to join their chosen field of study. Consequently, the majority of students assigned to study physics are considered to lack interest, be low achievers and lack academic success (Getenet, 2006).

1.9 Theoretical Framework

This research is based on the constructivist theory of learning. Constructivism is a theory about knowledge and learning that describes both what knowing is and how one comes to know (von Glaserfeld & Steffe, 1991; Driver, et al., 1994). In this view, knowledge is not facts which can be memorized and repeated temporarily, but developmental, internally constructed and socially mediated (Fosnot, 1996). Also, knowledge is not treated as accurate representation of external things, situations and events but rather as a mapping of actions and conceptual operations that are viable in learners' experience (von Glaserfeld & Steffe, 1991). With this view, scientific knowledge is tentative in nature and progressive that leads to approximations of ultimate natural phenomena (Lederman & O'Malley, 1990). This means that scientific knowledge is not a copy of reality.

The constructivist theory of learning emphasizes the influences of students' conceptions in their learning. In addition, studies (e.g., Baser & Geban, 2007; Dykstra, Boyle & Monach, 1992; Guruswamy, Somars, & Hussey, 1997) show that students come to science classrooms with pre-instructional conceptions that are often inconsistent with scientific concepts to be taught. Accordingly, students' conceptions are either barriers or bridges to their new learning (Sewell, 2002). In other words, if students' conceptions are consistent with the scientific conceptions to be learned, it can be used as bridges in the new learning. However, if their conceptions are inconsistent with the scientific conceptions, it will cause barriers to the new learning. In other words, the theory focuses on the process of knowledge construction by individuals under the influence of social contexts. Hence, this study is based on constructivist theory of learning due to the fact that conceptual change is a process of knowledge construction and reconstruction (Pinarbasi et al., 2006; Vosniadou, 2007).

Subsequently, the theory requires primarily the identification of existing students' conceptions (Vosniadou & Brewer, 1987), which constitute both valid and invalid knowledge. In addition, there is a claim of epistemological and ontological perspectives that refers knowledge to individual experiences rather than to the world and it is constituted by individual conceptual structures (Vosniadou & Brewer, 1987). In this case, conceptual structures constitute knowledge when individuals regard them as viable in relationship to their experiences. Hence, in this view, students' conceptions refer to students' personal understanding of concepts from their epistemological and ontological perspectives (Abell & Eichinger, 1998; Treagust & Duit, 2008).

From the epistemological perspective, students' conceptions are viewed based on how they describe the concepts being investigated; while from the ontological perspective, students' conceptions are viewed based on how they view the nature of the concepts being investigated.

This means that these epistemological descriptions and ontological considerations of students on the concepts being investigated can form patterns in student's conceptions (categories of conceptions). Therefore, to identify and categorize students' conceptions, this study follows an inclusive perspective that involves students' epistemological descriptions and ontological considerations of concepts in electricity and magnetism.

Constructivism is seen as a contemporary theory of learning in science in which knowledge is not transmitted but is constructed by active learners' mental interaction with the physical and social world (Fosnot, 1993). In line with this theory and the context of this study, interactive computer simulations can enhance the interaction of students in their learning of concepts that involve the microscopic physical world. This is because computer interactive simulation is used as one of the constructivist learning approaches in physics to facilitate students' active engagement in the construction and reconstruction of conceptual knowledge (Jimoyiannis & Komis, 2001).

In addition, according to Vygotsky (1978), cognitive development begins with an interaction between the learner and a more knowledgeable other (students in a group or a teacher), and the social processes are then transformed into the learner's internal mental processes. In other words, social interaction among individuals plays an integral part in how people learn (Rogoff, 1984; Harland, 2003). Student-student and student-teacher interactions in a classroom are important components of learning from the constructivist perspective. To the Vygotskian view, the role of a teacher in "scaffolding" and "anchoring" students' learning provides guiding social interaction. Based on this theory, one important step in designing instruction to develop complex mental functions is the consideration of the "zone of proximal development", the gap between the actual developmental level that is reflected in the learner's independent learning and the more scientific level that is accomplished with guidance. Most importantly, the zone of proximal development is created in the interaction between students and the instructor and/or among the students in a group (Vygotsky, 1978).

Currently, conceptual change is viewed as both a gradual process (evolutionary) and a sudden shift of theory (revolutionary) (Keiny, 2008). In the revolutionary conceptual change, coherent student's conception is put into conflict with the scientific conception. In this process, students need to have a certain amount of prior knowledge and a certain degree of reasoning abilities to reach a stage of meaningful conflict that enable them to grasp the idea of the conflict and to understand the scientific conceptions (Limon, 2001). The evolutionary conceptual change is a gradual process that considers intermediate conceptions developed during the change process (Maloney & Siegler, 1993). Hence, the paths for conceptual change may vary from student to student and are based on the contexts in which students engage.

Therefore, the inclusive epistemological-individual and social constructivist theory of learning- (Duit & Treagust, 2003; Vosniadou, 2007) was used as a theoretical basis for enhancement of the students' conceptual change. This theory takes into account what the learners already know and that acknowledges students' personal and social construction of knowledge. Embedded in the individual and social constructivist theory, the cognitive perturbation strategy proposed by Li et al., (2006) is used to promote conceptual change based on the idea that paths of conceptual change for different students are idiosyncratic, diverse and context sensitive.

1.10 Definition of Key Terms/Phrases

Concept: A perceived regularity in events or objects, or records of events or objects, designated by a label (mostly by a word) (Novak, 2002).

Students' Conceptions: Pre-existing (pre instruction) understanding of learners that influences their new learning (Sewell, 2002). Some earlier studies have given a combined term to both students' alternative conceptions and conceptual knowledge in a given conceptual domain of science, like students' preexisting understanding (Sewell, 2002) or students' mental model states (Bao & Redish, 2006), Therefore, the term students' conceptions encompasses both alternative conceptions (misconceptions) and conceptual knowledge of students in this study.

Conceptual Knowledge: Student's conception that is consistent with the scientific conception (expert-like knowledge). It is an explicit understanding of a concept and/or of the interrelations between concepts in a domain of knowledge (Rittle-Johnson & Alibali, 1999; Streveler, Litzinger, Miller & Steif, 2008).

Alternative Conception: Student's conception that is inconsistent with the scientific conception (Gilbert & Watts, 1983; Pinarbasi, Canpolat & Bayrakceken, 2006).

Conceptual Change: A learning process in which students' alternative conceptions transform (restructure) into the intended scientific conceptions (Pinarbasi et al., 2006; Vosniadou, 2007).

Epistemological Perspective: A view on students' conceptions based on how they describe a concept being investigated (Abell & Eichinger, 1998; Treagust & Duit, 2008).

Ontological Perspective: A view on students' conceptions based on how they consider (view the nature) a concept being investigated (Abell & Eichinger, 1998; Treagust & Duit, 2008).

Categories of Students' Conceptions: A classification of students' conceptions which are depicted on the bases of their epistemological descriptions and/or ontological considerations of physics concepts. This classification encompasses both categories of alternative conceptions and conceptual knowledge.

1.11 Summary of the Chapter

This introductory chapter describes the background and statement of the problem, objectives, research questions, significance, delimitation, limitations, context, theoretical framework and finally key terms/phrases of the study. The chapter starts by discussing the nature of electricity and magnetism which plays a central role in determining the structure of the natural world and becomes the foundations of most current and emergent technologies. Next, it discusses the inadequacy of the sole identification of alternative conceptions and the need for categorization of students' conceptions in electricity and magnetism. Consequently, the need to investigate students' conceptual change strategy which is believed to enhance their learning in the abstract concepts of electricity and magnetism is described. This study is based on constructivist theory of learning due to the fact that conceptual change is a process of knowledge construction and reconstruction. It is delimited to epistemological and ontological perspectives of conceptual change to categorize and then change students' conceptions in two broad conceptual areas of electricity and magnetism, the electric potential and energy (EPE) and the electromagnetic induction (EMI).

CHAPTER 2

REVIEW OF RELATED LITERATURE

2.1 Introduction

This study aims to investigate students' conceptual change in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) by supporting their learning through the cognitive perturbation strategy using interactive physics simulations. In order to investigate students' conceptual change, literature related to students' conceptions and conceptual change in the concepts of electricity and magnetism are reviewed. In addition, categories of students' conceptions, the theory of classical conceptual change and the role of cognitive conflict strategy in conceptual change are discussed. Besides, the need for cognitive perturbation strategy and the roles of interactive physics simulations and concept maps in conceptual change are presented.

2.2 Alternative Conceptions in Electricity and Magnetism

One of the fundamental goals of research in physics education is to improve students' understanding of physics concepts (McDermott, 2001). To this end, studies on students' conceptions have been done since the last three decades. The theory of classical conceptual change (Posner et al., 1982) has been used as the basis in the studies of students' conceptions. In physics, much of these studies have been done in the classical mechanics and in DC circuits (Baser, 2006; Baser & Durmus, 2010; Bilal & Erol, 2009; McDermott & Redish, 1999; Minstrell, 1982; Ramadas et al., 1996; Rosentha & Henderson, 2006).

In physics, the concepts of classical mechanics and DC circuits are closest to students' immediate everyday experience. Consequently, this closeness of the concepts to the students' everyday experience makes them to be certain in their conceptions (Planinic et al., 2006). Empirical studies on students' conceptions of the above-mentioned familiar science areas (e.g., Clement, 1982) showed consistent features of students' conceptions. For example, force implies velocity (Halloun & Hestenes, 1985) is the mostly revealed consistent students' conception about motion of macroscopic objects in introductory mechanics.

Studies revealed consistent students' conceptions in DC circuits. Students' conceptions in this area were studied at different levels of physics learning from schools to universities. Consistent conceptions were documented, like the unipolar or sink conception (Fredette & Lochhead, 1980; Osborne, 1981), the clashing or two-component conception (Osborne, 1983), the current consumption or sequence (attenuation) conception (Osborne, 1983; Shipstone, 1984), the constant current source conception (Borges, 1999) and the scientific Ohm's Law conception (Borges, 1999). All of these mentioned conceptions are alternative conceptions with the exception of the Ohm's Law scientific conception. Besides these, undergraduate students' conceptions of DC circuits were reported and documented in the literature (Engelhart & Beichner, 2004; McDermott & Shaffer, 1992). For example, current is consumed and that a battery is a source of constant current (Fredette & Lochhead, 1980; Licht & Thijs, 1990; Osborne, 1981); current originated at the positive terminal and is exhausted at the negative terminal (Rosenthal & Henderson, 2006).

In magnetism, Borges and Tecnico (1998) investigated five conceptions in the context of Brazilian students. These conceptions were: magnetism as pulling, magnetism as a cloud, magnetism as electricity, a magnet as an electrified object and magnetism as a field. The first four were the students' alternative conceptions while the last field model was an acceptable scientific conception.

However, the other concepts of electricity and magnetism, such as electric potential, electric potential energy, induced current, induced emf and fields are unfamiliar to students' everyday experiences and are abstract and invisible. Students face most of these concepts in their formal classroom learning. Accordingly, it is thought that students could have inconsistency in their conceptions of these concepts, and therefore needs to be investigated.

The effects of electric and magnetic fields confuse many students' understanding. Students show misunderstanding and inconsistencies indicating that they do not have a coherent framework of ideas about electricity and magnetism concepts (Maloney et al., 2001). For example, students have ideas that charges are attracted to magnetic poles and are pushed along magnetic field lines (Maloney, 1985; Scaife, & Heckler, 2010).

The scientific Ohm's Law concept of DC circuits influences students' understanding in the other parts of electricity and magnetism. For example, most students regard Ohm's law as the most important concept in electricity and magnetism (Leppavirta, 2012; Thong & Gunstone, 2008). This conception makes them to have difficulties in applying ideas of energy and work in the contexts of electric and magnetic fields (Saglam, & Millar, 2006). In addition, students at university level perceived a neutral object as an object with no charge and a charged body contains only one type of charge (Baser & Geban, 2007).

Students often face difficulties and have alternative conceptions due to their lack of understanding Newton's laws in the contexts of electricity and magnetism (Galili, 1995). For example, a larger force is exerted by a larger charge in the Coulomb's interaction between two charges (Leppavirta, 2012; Maloney et al. 2001) and a uniform electric field implies a uniform velocity of a charge placed in the field (Planinic, 2006).

Studies on the assessment of students' difficulties in the concepts of electricity and magnetism (Chabay & Sherwood, 2006; Planinic, 2006) have shown that the concepts are significantly more difficult to understand than the concepts in mechanics. They added that student' difficulties of most electricity and magnetism concepts remain the same; before and after instruction. Furthermore, the difficulties in electricity and magnetism concepts have similar trends across undergraduate students in different countries (American and Croatian) (Planinic, 2006) and upper high school students in Turkey and England (Saglam & Millar, 2006). This shows that students have problems with the concepts of electricity and magnetism globally and may cause problems in physics learning.

2.3 Categories of Students' Conceptions

As described in paragraph two of Section 1.2, the current view of identifying students' alternative conceptions and difficulties is changing towards the emerging view of knowledge structures and categorization of conceptions (Rebello, Zollman, Allbaugh, Engelhardt, Gray, Hrepic, et al., 2005) because of the complexities of students' conceptions in the microscopic world of physics. Consequently, as defined in Section 1.10, categories of alternative conception are a classification of depicted students' conceptions based on epistemological descriptions and/or ontological considerations of physics concepts. Hence, according to the definition given in Section 1.10, students' conceptions constitutes of categories of alternative conceptions and conceptual knowledge that are reviewed in the next two sub sections.

2.3.1 Categories of Alternative Conceptions

As introduced earlier, alternative conceptions are known as pre-instructional conceptions that are often inconsistent with scientific concepts to be taught. In literature, it is also described as a theory-like student idea (Ioannides & Vosniadou, 2002), misclassification of concepts within or across ontological categories (Chi, 2008; Chi & Slotta, 1993) or fragmented "pieces" of knowledge (diSessa, 1993; diSessa, et al., 2004). These distinctions are made noticeable based on the nature and structure (representation) of students' descriptions on concepts.

The different perspectives on students' alternative conceptions put science teachers in general and physics teachers in particular in indecisive situations with regards to the change of alternative conceptions of their students. As discussed in paragraph two of Section 1.2, the only identification of students' alternative conceptions in a given domain of science is believed to be inadequate for the design of learning supportive approaches for conceptual change. The inadequacy of this process is because of the different disputable perspectives on students' alternative conceptions and conceptual change. In addition, earlier researches (e.g., Chi & Roscoe 2002) have raised blurred ideas about students' conceptions. As they showed, alternative conceptions have different meanings due to the different ways they are formed. This complexity of alternative conceptions has also posed problems to students' conceptual change because they imply different ways of conceptual change.

In this study, a categorization of alternative conceptions is made by viewing students' descriptions of concepts from epistemological and ontological perspectives of conceptual change. This categorization of alternative conceptions is believed to reduce the complexity of the conceptual change process and be more useful than only the identification of the alternative conceptions themselves because the type of alternative conception categorized would indicate the type of conceptual change needed.

Thus, four categories of alternative conceptions can be discerned in the literature of cognitive science and science education based on the distinctions noticed in the students' descriptions (Chi, 2008; Chi & Slotta, 1993; diSessa, 1993; diSessa, et al., 2004; Ioannides & Vosniadou, 2002; McCloskey, 1983). Consequently, categories of alternative conceptions are meant for classification of the students' alternative conceptions that are depicted on the basis of the nature and structure of the students' descriptions of science/physics concepts. These categories are naïve physics (diSessa, 1982; McCloskey, 1983), ontological alternative conception (Chi, 2008; Chi & Slotta, 1993), lateral alternative conception (Chi, 2008; Chi & Slotta, 1993) and the Ohm's p-prim (diSessa, 1993). The distinctions among these categories are highlighted in the subsequent paragraphs.

Naïve physics: In this context, naïve physics is an intuitive physics (diSessa, 1982; McCloskey, 1983) defined as a simplified and less organized students' theoretical view of a concept or knowledge experientially acquired. For example, Aristotelian "force implies velocity" is naïve physics. Scientifically, Newtonian mechanics states that force implies acceleration but no force implies a zero velocity or a constant non-zero velocity. Accordingly, naïve physics have some valid elements of a concept or a principle of the physical world. In other words, it represents insufficient ideas or particular cases of a concept or a principle. In the area of electricity, for example, students' conception of a charge that moves in the direction of an electric field is naive physics. This is so because the conception is valid in a special situation when a point positive charge is released in an electric field but it does not apply for a negative charge or a charged particle projected with some angle to the direction of an electric field. In general, naïve physics is an "incomplete scientific model" or "incomplete mental model" (Chi, 2008) depicted by naïve learners.

Ontological alternative conception: According to Chi (2008), categorization is a process of identifying or assigning a concept to a category to which it belongs and is therefore assumed as an important process in physics learning. Most of the concepts in physics have attributes of being classified into categories based on their nature, properties, and descriptions. In an ontological categorization of science concepts, matter and process are two main ontological categories or representations (Chi, 2008; Chi & Slotta, 1993). For example, several teachers use tap water analogy in teaching their students about the electric current concept. However, at the end of the lesson some of the students may consider electric current as a fluid. It is known that electric current is a process in relation to charge flow, while water is a substance. This means, in such instruction, some students could conceive current as a fluid. It is such students' incorrect categorization of concepts which in this study is called *ontological alternative conception*.

Lateral alternative conception: Students may misclassify concepts within an ontological category (Chi 2008). It means that a concept in a hierarchy of concepts could be incorrectly categorized into different branches. For example, young children conceive the Moon as a living thing (animism) and an artifact (Venville et al., 2012). In addition, students may consider electric potential as a force, i.e., they incorrectly label electric potential under some properties of force. Though electric potential and Columbic force can share some properties and they are found in the same ontological category, laterally, they belong to different sub-categories. It is such a conception which in this study is called *lateral alternative conception*.

Phenomenological primitive (P-Prime): According to diSessa (1993), Phenomenological primitive is spontaneous physics which is made up of smaller and more fragmented cognitive structures. The p-prime can have different forms depending on how students respond to the concepts to be investigated. These forms are *actuating agency, dying away, resistance and interference, and Ohm's P-Prime* (diSessa, 1993; Hammer, 1996). In general, the first three forms of the p-prime can be related to students' conceptions of relating proximity to intensity (closer means stronger) (Hammer, 1996). For example, to a question of why it is hotter in the summer than in the winter, students' response may be that the earth is closer to the sun in the summer.

Among the different forms of the p-primes described by diSessa (1993), the Ohm's P-Prime, which means more effort creates more result, is relevant to this study. The Ohm's p-prime is one of the phenomenological primitives (diSessa, 1993) that may be reflected by physics students who consider Ohm's law as a fundamental law of electricity and magnetism. In Ohm's Law, the electric potential difference is the agent that creates an electric current against a resistance in an electric circuit. The higher the effect (electric potential difference) is the higher the result (current) and the higher the resistance the less the current will be in a circuit. Thus, students' conceptions in the other parts of electricity and magnetism concepts could be influenced by the

Ohm's Law of electric circuits. For example, in the Columbic interaction of two different charges, students may consider an exertion of a larger force because of a larger charge (Maloney et al., 2001; Leppävirta, 2012). In this case, the students simply relate larger force to larger charge and smaller force to small charge without considering the existence of action and reaction force in a system of the two charges.

2.3.2 Categories of Conceptual Knowledge

Conceptual knowledge is defined as an understanding of the structure of concepts and the relations among concepts (Tennyson & Cocchiarella, 1986). Complementary to this, Rittle-Johnson (2006) defined conceptual knowledge as the understanding of principles governing a domain and the interrelations between concepts in the domain. This definition illustrates that concepts such as force or energy, as well as relationships such as Newton's laws and the laws of energy and momentum conservation, are part of conceptual knowledge in the domain of physics.

Conceptual knowledge plays a crucial role in how we make sense of the world because it allows us to categorize concepts and it also impacts what we do with what we have categorized (Perkins, 2006). This means conceptual knowledge is more complex than declarative knowledge (the "what" of a concept, i.e., definition or factual knowledge) and influences procedural knowledge (knowledge of subject-specific techniques and methods), such as knowledge of problem solving in physics.

Rittle-Johnson et al. (2001) discussed some mechanisms through which conceptual knowledge may enhance procedural knowledge. First, conceptual knowledge may help students identify key features of a problem in a domain of science. This could help them to apply their conceptual knowledge in problem solving by properly understanding the problem and generating a successful solution (Redish and Smith, 2008). Second, conceptual knowledge may help students recognize errors in their problem solving procedures. Third, conceptual knowledge may influence the generation of new procedures by helping students identify and evaluate essential elements of correct procedures. In general, conceptual knowledge is knowledge of classifications and categorizations, principles and generalizations, and theories, models and structures in an area of science. Accordingly, conceptual knowledge in physics could be categorized into hierarchical, relational and scientific models.

Hierarchical conceptual knowledge: This is classification and categorization of concepts into correct ontological and/or lateral categories (Chi, 2008). In addition, an organization of concepts from a more to less inclusive concept(s) can be named as hierarchical conceptual knowledge.

Relational conceptual knowledge: According to Long (2005), the construction of relationships between pieces of information is one form of achieving conceptual knowledge. In other words, it is meant for valid qualitative relationships between two or more concepts, like relationship between electric potential and charge.

Scientific model: This is a “correct scientific mental model” (Chi et al., 1994; Vosniadou & Brewer, 1994) that may represent changes and generates predictions and outcomes, such as prediction of the direction of electric field of a given source.

2.4 Conceptual Change

The theory of conceptual change was first developed by science education researchers and philosophers in the early 1980's (Posner et al., 1982). The theory was based on both Piaget's notion of disequilibration and accommodation and Thomas Kuhn's description of scientific revolution (Kuhn, 1970). As defined in Section 1.10, conceptual change is a learning process in which students’ alternative conceptions transform or reconstruct into the intended scientific conceptions (Vosniadou, 2007). Hence, this theory is based on the constructivist theory of learning (Hewson & Thorley, 1989), because it involves guiding of students to reconstruct their alternative conceptions towards the intended scientific conceptions (Pinarbasi et al., 2006).

Since the last three decades, different types of conceptual changes have been distinguished. These distinctions are based on different perspectives of researchers in the area. Accordingly, from the epistemological perspective, conceptual change is viewed as *assimilation* and *accommodation* of concepts. “Assimilation” (Posner et al., 1982) or “conceptual capture” (Hewson, 1981) of concepts refers to the use of existing conceptions to deal with new (scientific) conceptions while “accommodation” (Posner et al., 1982) or “conceptual exchange” (Hewson) involves replacing the learner's persistent conceptions. These two forms of conceptual change, assimilation and accommodation, respectively, are also named as "weak restructuring" and "radical restructuring" (Carey, 1985), because the former involves modification or incorporation of the existing conceptions while the latter involves the rejection of the existing conception and the acceptance of a new conception.

Analogously, from ontological perspective, conceptual change is distinguished as "*tree jumping*" and "*branch switching*" (Chi, 2008; Thagard, 1990) to distinguish the conceptual restructuring from incorrect to correct ontological categories. In this perspective, *branch switching* is meant for rearrangement of concepts within an ontological category, while *tree jumping* is meant for restructuring of concepts in different categories.

2.4.1 Classical Conceptual Change Model and Its Limitations

In the model proposed by Posner et al. (1982), four conditions for conceptual change were specified. In this model, Posner et al. suggested that learning occurs when the learner recognizes a need and becomes *dissatisfied* with existing concepts. For students to change their alternative conceptions, the scientific conceptions should appear *intelligible*, *plausible*, and *fruitful* to them (Hewson & Thorley, 1989). In other words, this model suggests creating dissatisfaction in students with their alternative conceptions so as to strengthen the status of the desired scientific conceptions. Consequently, according to Posner et al. (1982), the four conceptual change conditions are:

1. Dissatisfaction - students must become dissatisfied with their existing conceptions;
2. Intelligibility - the new concept must be clear and understandable for students;
3. Plausibility- the current problem should be solved using the new concept; and
4. Fruitfulness- similar future problems can be solved by using the new concept.

Based on these conditions, conceptual change learning approaches have been developed and demonstrated positive effects in promoting students' conceptual understanding of science (Gabel, 1998; Hand & Treagust, 1991; Hewson & Hewson, 1983; Stofflett & Stoddart, 1994).

Conceptual learning approaches were mainly developed from 1980s to 1990s in science concepts learning and appeared more efficient than the traditional approach (Duit & Treagust, 2003). Some of these approaches were bridging analogies (Stavy, 1998), disequilibration techniques/ cognitive conflict (Hewson & Hewson, 1984) and learning cycles (Dykstra et al., 1992). These approaches were based on conceptual change models and cognitive ideas and are known as classical conceptual change approaches.

These classical conceptual change approaches appear more efficient than traditional transmission models (Posner et al., 1982). This is because a number of studies (Dykstra et al., 1992; Grayson, 1994; Hake, 1998) have shown that conceptual change in physics cannot be achieved solely by traditional teaching. However, difficulties and limitations of such approaches were studied and reported (Chan et al., 1997; Demastes et al., 1995; Dreyfus et al., 1990; Limon, 2001; Zohar & Aharon-Kravetsky, 2005). The classical conceptual change approaches have limitations due to the complex nature of students' alternative conceptions (Duit & Treagust, 2003). That is, the idiosyncrasy and diversity found in students' conceptual development and the vacillation of students' conceptions from one context to another (Li et al., 2006) constraining conceptual change learning. Indeed, it could be argued that the classical conceptual change approaches are inadequate and need to be reformed to promote conceptual change.

2.4.2 The Role of Cognitive Conflict Strategy in Conceptual Change

Cognitive conflict (Hewson & Hewson, 1984) is one of the strategies of a classical conceptual change model which has been mostly implemented in the learning of science concepts. It constitutes of a crucial stage in the influential conceptual change model proposed by Posner et al. (1982), however, its difficulties and limitations have been reported. For instance, studies (Chan et al., 1997; Demastes et al., 1995; Dreyfus et al., 1990) attest that it is difficult for all students to reach a stage of meaningful cognitive conflict. In addition, there exist discrepancies among students in their willingness to confront and resolve cognitive conflicts (Chan et al., 1997). Thus, current research indicates that the cognitive conflict approach has dissimilar effects for students of different academic levels. In this regard, studies (Limon, 2001; Zohar & Aharon-Kravetsky, 2005) indicate that the cognitive conflict strategy can benefit students with high academic achievements while it hinders progress of students with low academic achievements. In addition, as discussed in Section 1.2, students' responses to scientific conceptions are influenced by their prior knowledge (Chinn & Brewer, 1993). That is, if students have little or inconsistent conceptual knowledge about a topic or minimal level of conceptual knowledge, like in abstract and complex concepts of electricity and magnetism, then cognitive conflict would not be meaningful at all. As discussed in Section 1.2, this is because of the inconsistency of students' conceptions that are found at low levels and the wide cognitive gap that exists between their prior conception and scientific conception. As a result, it is less likely to expect effective students' conceptual change.

Many of the difficulties found in the application of the cognitive conflict strategy are closely related to the complexity of factors intervening conceptual learning in the context of classroom settings. These are, firstly, the success of cognitive conflict approach depends strongly on the ability of the individual student to recognize and resolve the conflict (Limon, 2001). This means that several intellectually less able students may fail to even recognize the conflict and some of those who do recognize it may not be able to resolve it (Planinic et al., 2005). Secondly, students are generally reluctant or unwilling to abandon their alternative conceptions formed upon their own experience (Chan et al., 1997; Planinic et al., 2005). However, scientific conceptions are often difficult to understand by the students because they are not grounded in their experience (Planinic et al.). Therefore, this remoteness of scientific conceptions from the students' experience could create frustration in physics students who have less confidence in their conceptual knowledge of concepts in electricity and magnetism and consequently, see it as a confirmation of their inability to learn physics.

There are controversial results regarding the effectiveness of cognitive conflict in learning science concepts. According to Lee and Byun (2012) and Zohar and Aharon-Kravetsky (2005), students usually own inconsistencies in a superficial way rather than undergo more radical kinds of changes implied by the conceptual change theory. This would be one of the reasons that have contributed to the current prevalent perspective that views conceptual change as a gradual process (evolutionary) rather than a sudden shift of theory (revolutionary) (Vosniadou, 1999). As Chan et al. (1997, p 2) argue,

> Despite much enthusiasm for a conceptual conflict approach, findings have been equivocal. Even when students are confronted with contradictory information, they are often unable to achieve meaningful conflict or to become dissatisfied with their prior conceptions.

In addition, Limon (2001) appraised a series of explanations given in the literature why the cognitive conflict strategy often seems not to work in the classroom, at least to the extent expected. As she summarized, students need to have a certain amount of prior knowledge and a certain degree of reasoning abilities to reach a stage of meaningful conflict that enable them to grasp the idea of the conflict and to understand the scientific conceptions.

In general, the cognitive conflict of the classical conceptual change model has been proposed and viewed as a linear, rational, deterministic, one step and revolutionary process of conceptual change (Nussbaum & Novice, 1982; Tao & Gunstone 1999). Nevertheless, it could be suggested that perhaps this process may have different paths for different learners, not always being linear and revolutionary. We still lack a more scientific knowledge of the intermediate states of the conceptual change process that would be based on the contextual need of learners. Therefore, it would be necessary to challenge alternative conceptions of students in different contexts of classroom setting and to overcome the limitations of cognitive conflict strategy that may appear in students' learning of selected electricity and magnetism concepts.

2.4.3 Conceptual Change Research in Electricity and Magnetism

Investigations done to develop students' conceptual change were mainly in DC electric circuits (see paragraph one of Section 1.2). For example, the effectiveness of potential difference approach in relation to the usual current concept approach (Rosenthal & Henderson, 2006), the use of analogy with the four-step constructivist teaching model (elicit-engage-explanation-extension) (Ipek & Calik, 2008), conceptual change simulations over the traditional confirmatory simulations (Baser, 2006) and the effectiveness of computer-supported versus real laboratory inquiry learning environments (Baser & Durmus, 2010) on pre-service teachers. In addition, there was supposition to address students' difficulties and alternative conceptions in electricity and magnetism using techniques that could visualize field patterns (Saglam & Millar, 2006). For its realization, Stocklmayer (2010) investigated the success of the field-model as an alternative approach to teaching of DC concepts in high school.

However, the other parts of EM concepts, like electromagnetic induction and electric potential and electric energy in which most students across different countries face difficulties with (Planinic 2006; Saglam & Millar, 2006) have not been well addressed. In addition, there was no designed technique that can facilitate to address the complexities and idiosyncrasies (Li et al., 2006) and inconsistencies as well as fragmentariness of students' conceptions (Albe et al., 2001; Greca & Moreira, 1997), like students' conceptions often appear in electricity and magnetism. Such conceptions might need different learning paths (trajectories) for different students or groups of students as an instructional strategy (Baser & Geban, 2007; Chinn & Samarapungavan, 2009). The details of the chosen supportive approach are discussed in the subsequent sections.

2.4.4 The Need for Cognitive Perturbation Strategy

Students lack strong confidence and do not have a firm stand on their conceptual understanding of electricity and magnetism concepts because of the abstract relations existing in the EM concepts (Chabay & Sherwood, 2006). In addition, several undergraduate students scored low results in conceptual diagnostic tests of electricity and magnetism (Finkelstein, 2005; Planinic, 2006). Consequently, these low scoring students failed to change their alternative conceptions with the cognitive conflict strategy (Limon, 2001; Zohar & Aharon-Kravetsky, 2005). The reason is that students' responses to electricity and magnetism conceptual tests/questions are inconsistent, unlike in mechanics. In classical mechanics, students are quite confident in their answers although many of their answers are incorrect. Accordingly, consistent alternative conceptions may be recognized through incorrect answers provided with high concentration of students (Bao & Redish, 2001). Thus, it would be difficult to make students dissatisfied with their alternative conceptions and set them into a state of cognitive conflict because of unstable students' alternative conceptions of the concepts in difficult conceptual areas of EM, like electric potential and energy and electromagnetic induction.

As described in Section 1.2, the fundamental idea of cognitive perturbation strategy is based on the understanding that paths of conceptual change for different students/groups of students are idiosyncratic, diverse and context sensitive (Li, 2011; Li et al., 2006). The types of perturbations necessary for initiating conceptual change would be determined by contexts in which students engage. Li et al. proposed and implemented cognitive perturbation strategy through computer-supported dynamics modeling learning environment in a qualitative study of a single group of elementary science students' conceptual change and in particular they investigated the progression of elementary science students' conceptual knowledge in the topic of evaporation. However, the effectiveness of this strategy in the presence of a controlled group in a classical conceptual change learning model has not yet been investigated at any educational level. Therefore, a study is needed on the effectiveness of cognitive perturbation strategy in relation to cognitive conflict strategy to contribute knowledge to the theory of conceptual change in science learning.

The cognitive perturbation strategy differs from the classical conceptual change approach in a number of ways. In the classical conceptual change, students' conceptions are often demarcated as either alternative conceptions or scientific conceptions, but the cognitive perturbation strategy considers the intermediate conceptions developed during the change process (Maloney & Siegler, 1993). In addition, Li et al. (2006) argue that the classical conceptual change approach suffers from lack of sensitivity to classroom social contexts essential for conceptual change. With these views, students fail to make sense of the discrepant events in complex concepts like electricity and magnetism and maintain their alternative conceptions after instruction (Chabay & Sherwood, 2006; Finkelstein, 2005). Thus, the cognitive conflict in the classical conceptual change model could have limitations to provide appropriate conceptual anchors to bridge the gap between the students' alternative conceptions and scientific conceptions.

Cognitive perturbation strategy is based on the constructivist theory of learning (Driver et al., 1994), like cognitive conflict strategy (Hewson & Hewson, 1984) of the classical conceptual change approach. The cognitive conflict strategy often puts conflict between students' alternative conceptions and scientific conceptions intended to be taught. It rejects students' alternative conceptions at the beginning without considering the intermediate conceptions developed during the change process (Maloney & Siegler, 1993). However, cognitive perturbation strategy provides appropriate perturbations to initiate students' conceptual change towards more scientifically viable intermediate conceptions than their preconceptions, before suddenly reaching scientific conceptions (Li et al., 2006). In addition, the classroom contexts in which students would immerse determine the types of perturbations necessary for initiating conceptual change.

Moreover, the researcher believes that the need for cognitive perturbation is because of the supposition that students' alternative conceptions are inconsistently diversified due to their different background. For example, on a concept of electric potential, students would have different conceptions and consequently, different ways of learning are needed to support their learning. A student who consider electric potential as a force and another one who consider electric potential as a charge need different supports. In this case, contexts do not mean the contexts of the problems but they are students' different contextual needs or different ways to address states of conceptions. Hence, during the learning of an individual student/group of students, their contextual needs are decided by the facilitator of the learning. This is the reason that cognitive perturbation is initiated based on the students' contextual needs.

Therefore, the purpose of cognitive perturbation strategy is different from that of the cognitive conflict strategy. The cognitive conflict strategy of the classical conceptual change starts with conflict and then rejects alternative conceptions. However, to initiate conceptual change with the cognitive perturbation strategy, the students are gradually provided appropriate perturbation from their preconceptions towards scientifically more viable intermediate conceptions before they are guided to scientific conceptions. This means, in this strategy, the students are not suddenly directed to face the scientific conceptions and engage in cognitive conflict with their alternative conceptions. Therefore, it is due to the aforementioned points that the cognitive perturbation strategy (Li et al., 2006) is intended to be used to achieve the desired conceptual change in selected conceptual areas of electricity and magnetism.

2.4.5 The Role of Interactive Simulations in Conceptual Change

The use of appropriate interactive visualization simulated software available for teaching concepts of physics in the classroom has become important to overcome the limitations of real experiments and helps students to construct their knowledge through less guided exploration (Urban-Woldron, 2009). In addition, computer simulations are used to provide discrepant events in conceptual learning because they have the capacity to provide learners with an exploratory learning environment (Zacharia & Anderson, 2003). Computer simulations can also motivate and actively engage students towards construction of their knowledge. For example, the research of the Physics Education Technology (PhET) project (Wieman et al., 2008a) particularly related to simulation and students' motivation has developed more than 60 interactive simulations on the topics of physics. These simulations are freely available on the website (http:// phet.coloado.edu) and can be easily run online or may be downloaded to a local computer or installed to a CD (Wieman et al., 2008b). Moreover, if students in groups are given a chance to run the simulations, then the simulations can offer them opportunities to actively interact in their learning at reasonable scale and time frame. In short, the simulations are designed to be interactive, engaging, and also to make explicit certain visual representations (Wieman et al., 2008b). Rutten et al. (2012) reviewed 51 articles between 2001 and 2010 and found that simulations are useful for visualisation and reported large effect sizes of well-designed simulation-based instruction. Therefore, because of the complex and invisible phenomena in electricity and magnetism, interactive physics computer simulations of selected conceptual areas of the concepts are used as part of the supportive learning strategies.

2.4.6 The Role of Concept Maps in Conceptual Change

Concept maps are two-dimensional graphical representation of individuals' knowledge structure of a particular conceptual topic (Novak & Gowin, 1984). The theoretical basis for concept maps is the Ausubel-Novak-Gowin theory of meaningful learning (Novak & Gowin, 1984). In relation to this theory, the difference between meaningful learning and rote learning must be cleared. Rote learning occurs when learners make no effort to relate new concepts and propositions to their prior relevant knowledge, whereas meaningful learning occurs when learners seek to relate new concepts and propositions to their relevant existing concepts and propositions (Novak & Gowin, 1984). In other words, meaningful learning involves reorganization of existing knowledge or integration of new knowledge with existing knowledge. Therefore, this theory of learning considers concept and propositional learning as the basis on which individuals construct their own idiosyncratic meanings. This theory is among the three influential theories of learning (Ausubel's, Piaget's & Vygotsky's), which commonly agree on the influence of students' conceptions in learning and are the bases for the constructivist view of learning (Cakir, 2008).

Experts and novices are distinguished by the organization of their knowledge, and not by the content of their knowledge (Zajchowski & Martin, 1993). Expert's conceptual knowledge is structured around key concepts and principles (Hardiman, Dufresne, Robert & Mestre, 1989). In addition, an expert has contextually appropriate access to possession of knowledge (Redish, 1994). Such access could be shown by the structure of interconnections between knowledge elements (Mestre & Touger, 1989). Therefore, for the purpose of assessing students' conceptions with respect to physics concepts, a need exists for concept maps that can probe students' conceptual knowledge structure.

As mentioned earlier, most students do not have well developed models or conceptions in the microscopic physical phenomena of physics. In such cases the solely use of common research tools such as survey tests may be inadequate to understand students' ways of thinking (Rebello et al., 2005). A tool that may be particularly useful in exploring the dynamics of students' conception is needed as an additional method of data collection. Thus, to categorize students' conceptions of electricity and magnetism concepts, structural and relational writing discourse (Roth & Roychoudhury, 1994) of students as data collection instrument is found useful. In other words, concept maps are found useful for an in-depth exploration of learners' knowledge structures in the complex and abstract science concepts, like electricity and magnetism. The details of concept maps are discussed in the methodology section.

A *concept* means a perceived regularity in events or objects, or records of events or objects, designated by a label (mostly by a word) (Novak, 2002). In concept maps, concepts are included in boxes or ovals (see Figure 1.1). Concept maps have characteristic components to represent individual students' conceptions. These components are propositions, hierarchies, cross-links and examples (Novak & Gowin, 1984). *Propositions,* as a characteristic of concept maps, are meaningful relationships between concepts (Novak & Gowin, 1984; Novak, 2002). They are indicated by connecting lines and linking words and are used to measure students' ability of relating two or more concepts. *Hierarchy*, another characteristic of concept maps, refers to the breaking down of the super-ordinate concept into valid levels (subordinates), i.e., from the general to a specific concept (Novak & Gowin, 1984). It can measure students' ability of hierarchical categories and organizations of conceptual knowledge. Another characteristic of concept maps is the inclusion of cross-links (Novak, 2002). *Cross-links* are meaningful connections between concepts under different hierarchies of the concept-maps. Cross-links can indicate students' in-depth conceptual understanding in a domain of knowledge. *Examples* are the most specific differentiation of the subordinate concepts that help to clarify the meaning of a given concept. They are valid instances or illustrations of subordinate concepts that can measure individual's specific contextual understanding of the concepts. Usually *examples* are not included in ovals or boxes, since they are specific events or objects and do not represent concepts.

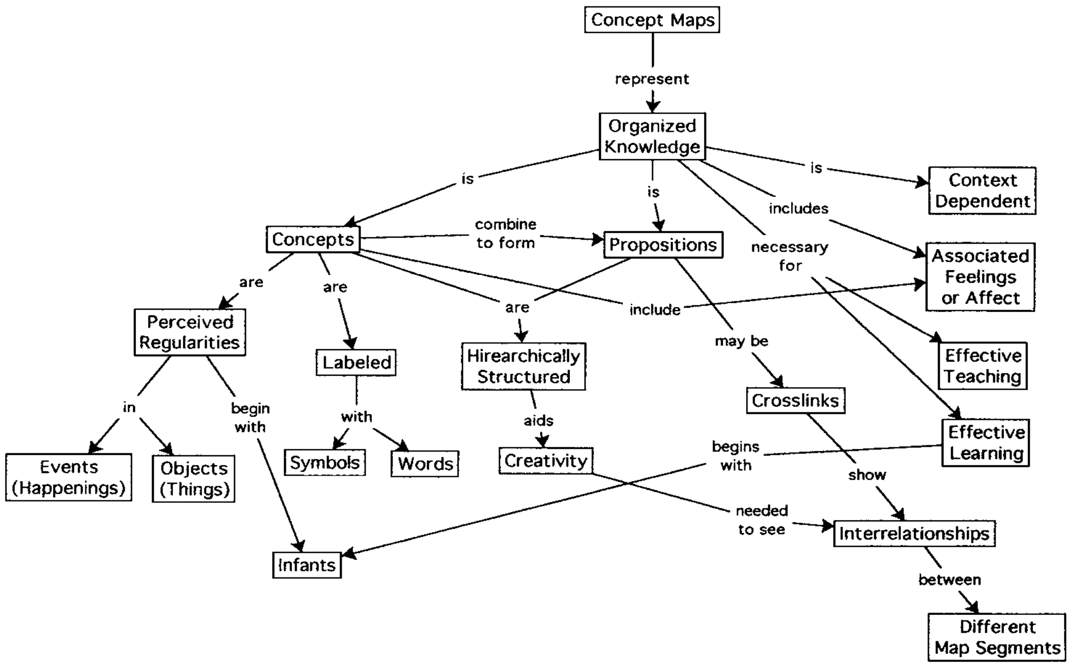

Figure 1. 1: Concept maps showing the nature and structure of concept maps (Novak, 2002)

A concept map, in its simplest form, is two concepts connected by a linking word to form a proposition. For example, 'force is a vector' is a single concept map that forms a valid proposition of the concepts force and vector. Accordingly, concept maps are formed by combination of more than two related concepts and propositions.

Concept maps can have hierarchical or non-hierarchical (e.g., cyclic or chain) structure based on the nature of the subject under investigation. Studies (Novak & Gowin, 1984; Zoller, 1990; Ruiz-Primo & Shavelson, 1996; van Zele et al., 2004) have pointed out that in subjects such as physics and biology the concept maps possibly reflect a hierarchical ordering of concepts whereas, in subjects such as chemistry, the underlying structure of knowledge is not necessarily hierarchical.

In general, concepts maps can be used for several purposes. They can be used to visualize and measure the depth, breadth and organization of an individual's knowledge (Huer, 2005), for identifying prior knowledge (Stoddart et al., 2000) and to reveal alternative conceptions (Mistades, 2009).

2.5 Summary of the Chapter

This chapter discussed the review of related literature. It involved review on students' conceptions and conceptual change in electricity and magnetism, categories of students' conceptions, the classical conceptual change model and its limitations, the role of cognitive conflict strategy in conceptual change, the role of computer interactive simulations in conceptual change, the need for cognitive perturbation strategy and the role of concept maps in conceptual change.

In the review of related literature, the students' difficulties in learning of the concepts of electricity and magnetism, such as electric potential, electric potential energy, induced current, induced emf and fields which are unfamiliar to students' everyday experiences and also abstract and invisible phenomena were discussed. In addition, review on categorization of students' conceptions was done by viewing students' descriptions of concepts in different literature from epistemological and ontological perspectives of conceptual change. This categorization of alternative conceptions was believed to reduce the complexity of the conceptual change process and be more useful than the only identification of the alternative conceptions themselves. Moreover, the limitation of classical conceptual change approaches, like the cognitive conflict, in the complex nature of students' alternative conceptions and the need for the cognitive perturbation and interactive physics simulations as a supportive learning strategy in the complex and invisible phenomena in electricity and magnetism were discussed.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This study encompasses two phases. The first is diagnosing the categories of students' conceptions in the concepts of EPE and EMI. The second is studying the impact of the cognitive perturbation through physics interactive simulations (CPS) in relation to the cognitive conflict through physics interactive simulations (CCS).

In order to diagnose the categories of students' conceptions in the concepts of EPE and EMI, qualitative data were collected using focus groups discussions (FGD) and students' concept maps (CM) and then analyzed separately using framework thematic analysis. The students scores on the Conceptual Survey of Electricity and Magnetism (CSEM) was used to form homogenous focus groups.

In order to study the impact of the CPS in relation to the CCS in enhancing students' conceptual change in the concepts of EPE and EMI, quantitative data were collected using the modified DEEM and CM and then analyzed separately using ANCOVA.

3.2 Research Design

Studies (Stavy, 1998; Vosniadou, 2007) have shown that the nature of the study of conceptual change is a very complex and gradual ongoing learning process. This is mainly because of the fact that students' conceptions vacillate from one context to another, and idiosyncratic features found in students' conceptual change are diversified (Li et al., 2006).

To address these concerns, therefore, this study employed a *quasi-experimental design* and used *concurrent mixed methods* research. Taking into account the limitations of exclusively relying on qualitative or quantitative research design, the mixed method research has emerged and is viewed as the third methodological movement (Johanson & Onwuegbuzie, 2004; Doyle et al., 2009). In other words, this study followed a pragmatic approach (Doyle et al., 2009) which encourages researchers to use different approaches for research questions that, in fact, cannot be thoroughly addressed using a single method.

3.2.1 Case Study

The basic idea of a case study is that a case (or perhaps a small number of cases) is studied in detail using whatever methods and data seen appropriate (Punch, 2009). Accordingly, the researcher sought a better understanding of a particular case (first year physics students of Ambo University) in relation to their conceptions and conceptual change of the concepts in EPE and EMI.

3.2.2 Quasi-experimental Design

As discussed in Section 1.3, this study investigated first year physics undergraduate students' conceptual change in selected conceptual areas of EM by supporting their learning in the context of Ambo University, Ethiopia. The students' learning was supported by two constructivist learning approaches, the CCS and the CPS, in which their effects were compared.

In a quasi-experiment, comparisons are possible because of natural occurring treatment groups that are fairly clear cut, though not set up for research purposes (Punch, 2009). Accordingly, the first year students enrolled at the Physics Department in 2010 were assigned to two lab groups by the Department. These two lab groups were taken as naturally occurring treatment groups. This means, there was no random selection of individuals to the groups, but the researcher had control over when to measure outcome variables (pre and post tests) in relation to exposure to the independent variables (the CPS and CCS). In addition, the researcher had statistical control over the variables with analysis of covariance (ANCOVA). Thus, a quasi-experimental design was appropriately chosen to study the students' conceptual change and compare the effects of the two constructivist supportive approaches.

3.2.3 Mixed Methods Research

Mixed methods research focuses on collecting, analyzing and mixing of both quantitative and qualitative data in a single study or series of studies for a better understanding of a research problem (Creswell & Clark, 2007). The selection for the mixed methods was to benefit from their complementary nature and non-overlapping limitations since mixed-methods has its goal of not to replace either of them but rather to draw from the strength and minimize the weaknesses of both in single research and across the approaches (Johanson & Onwuegbuzie, 2004). To this end, mixed concurrent quantitative and qualitative research approach was used to increase the validity of the study. In other words, mixed data collections were concurrently done in both pre and post treatments to better understand the research problem and triangulate the results for each research question. In short, triangulation design of multiple-methods was selected for this study.

3.2.3.1 Triangulation Design

The purpose of triangulation design is to obtain complementary qualitative and quantitative data on the same topic, bringing together the different strengths of the two methods (Creswell & Clark, 2007). It is a one phase design, where the two types of data are collected in the same time frame and are given equal weight. Typically it involves concurrent but separate collection and analysis of two types of data which are then merged at the interpretation of the results stage. Thus, in this study, qualitative and quantitative strands were conducted separately and concurrently and merged at the point of interpretation. They were believed to form a more complete understanding of the students' conceptions and conceptual change in abstract concepts of electricity and magnetism.

3.3 Research Sample

The research sample included 45 first year physics undergraduate students (aged between18 to 23) who were registered for the course electricity and magnetism in the year 2011 at Ambo University, Ethiopia. The students were assigned into two lab groups, group A and group B, by the Department of Physics. The department used the students' alphabetical order list, as usual, to divide the class into two lab groups. From the naturally existing two lab groups for the course, control and experimental classes were randomly assigned into cognitive conflict strategy using simulation (CCS) and cognitive perturbation strategy using simulation (CPS), respectively.

3.4 Instruments

This study employed a number of different data collection instruments, including conceptual tests, focus group discussions (FGD) and concept maps (CM). The tests were the Conceptual Survey of Electricity and Magnetism (CSEM) and a modified Diagnostic Exam of Electricity and Magnetism (DEEM) developed by Maloney et al. (2001) and Marx (1998), respectively. The CSEM was meant not to collect data for the research questions, but used to obtain data on the students' prior conceptual knowledge level and form approximately homogenous ability focus groups for discussions. The other multiple data collection methods (the modified DEEM, FGD and CM) helped to obtain an in-depth and corroborative understanding of students' conceptions and the process of conceptual change in the concepts of EPE and EMI.

3.4.1 The Conceptual Survey of Electricity and Magnetism

The Conceptual Survey of Electricity and Magnetism (CSEM) is a survey diagnostic test with 32 items developed by Maloney et al. (2001) to assess students' alternative conceptions and conceptual knowledge in conceptual areas of electricity and magnetism. It is a multiple-choice test with a combination of conceptual knowledge as a correct answer and alternative conceptions as distracters, because so far no test has been developed to test alternative conceptions alone. The CSEM has less number of items per conceptual area with each item measuring more than one concept. However, the test has been widely implemented in different contexts of physics education research related to electricity and magnetism (Maloney et al., 2001; Planinic, 2006; Pollock, 2008; Zavala & Alarcon, 2008). Therefore, the CSEM was believed to supply useful data to form approximately independent homogenous focus groups for discussions.

3.4.2 The Modified Diagnostic Exam of Electricity and Magnetism

The Diagnostic Exam of Electricity and Magnetism (DEEM) developed by Marx (1998) is a diagnostic test of 66 items with more items per conceptual area compared to the CSEM; each item measures conceptual knowledge of a particular concept. Compared to the CSEM, it provides more quantitative data because the CSEM has fewer items per conceptual area with each item measuring more than one concept. The correct responses in the DEEM represent answers commonly accepted by experts (scientific conceptions) concerning electricity and magnetism concepts while the distracters are based on students' most common alternative conceptions of those concepts. Its purposes are to measure overall achievement and progress of individual students and relate students' response patterns to alternative conceptions and to measure the effectiveness of a particular learning approach in electricity and magnetism (Marx, 1998).

The DEEM was modified and adapted for pretest and posttest in relation to conceptual contents in the two conceptual areas of electricity and magnetism selected for this study. All the conceptual areas of electricity and magnetism could not be dealt with due to time constraints, nature of the treatments and the unavailability and unsuitability of the interactive computer simulations. Some questions in the conceptual areas intervened were selected from the CSEM and from another test, the Diagnostic Test of Students' Ideas in Electromagnetism (DTSIEM), developed by Saglam & Millar (2004) and then added to the modified DEEM. Thus, the modified DEEM have fewer main items but more items per conceptual area based on the extent of conceptual areas intervened. It was accepted that, in so doing, a more detailed study of a smaller number of conceptual areas would be facilitated (Planinic, 2006). Thus, the DEEM was modified to 30 multiple choice questions with five options each (see Appendix A). Out of these conceptual questions, 16 were from the EPE and 14 were from the EMI concepts. The EPE included questions 1-14 and 17-18 while the EMI part included questions 15-16 and 19-30 (see Table 3.1).

Table 3. 1: Contents of the modified DEEM

Item No	EPE conceptual area
1, 2	Motion and energy of an electric charge in a uniform field
3,4,5,6,7	Electric potential of point charges
17,18	Electric potential of two point charges system
8,9,10,11	Electric potential energy of two point charges system
12,13,14	Equipotential lines, electric field, electric potential energy & work
Item No	**EMI conceptual area**
15,16	Induced current due to changing area of a loop
19,20, 21,22,26	Induced current due to motion of a loop in a magnetic field
23,24	Induced current due to a non-uniform magnetic field and motion of a coil
25	Induced current due to relative motion of a magnet and a coil
27, 28, 29, 30	Magnetic flux & Induced emf

3.4.3 Focus Groups Discussion

A focus group is defined as a research technique that collects qualitative data through group interaction on a topic determined by the researcher (Morgan, 1996). In other words, a focus group consists of small group of informed people who are engaged in a social process based upon the collection of discussion as data. It was originated previously, in social sciences research and developed to market research as a convenient method of obtaining data from clients and customers (Wilson, 1997). In addition, Wilson reviewed that much of the published research that used focus groups discussion as their method of data collection were in health-related fields.

However, focus group discussion has currently gained acceptability in academic institutions due to the insights it provides into participants' experiences (Jarrell, 2000). Its purpose is generally to stimulate conversations around carefully constructed questions that are initiated by the researcher for a specific purpose of obtaining data relevant to the research questions (Wilson, 1997). Specifically, focus group discussion in education research can be used to elicit participants' feelings, attitudes and perceptions about a particular topic through conversations (Parker & Tritter, 2006; Puchta & Potter, 2004). In addition, focus groups can be used to elicit students' view (Franklin & Knight, 1995), gather useful data about the effectiveness of an instruction (Lederman, 1990), evaluate students' knowledge (Bauchner, Boardman, & Palmer, 1996) and enhance survey results in education research (Panyan, Hillman & Liggett, 1997).

According to Wilson (1997), researchers who employ focus group discussion in educational research usually choose one of the following strategies. These are using focus groups:

- in combination with quantitative data collection to deepen the researcher's understanding;
- to help researchers understand previous data collected by quantitative methods; and
- in concurrence with other qualitative methods.

This study follows the last two options to strengthen the data obtained with both quantitative and qualitative methods. This means, firstly, the results of the focus groups discussions help to understand the quantitative results of data collected with diagnostic tests and concept maps.

Secondly, the qualitative results from focus groups discussions are triangulated with the qualitative results from individual students' concept maps.

In this study, four focus groups (two groups per treatment class) were formed. Their formation was based on the students' baseline conceptual knowledge, which was measured using their responses in the CSEM test (see Appendix B). The intention for using the test was to form approximately independent homogeneous ability students in each focus group discussion (see Section 3.6.2.1& Appendix B). It was believed that such grouping of students can reduce the influence of dominating participants in the discussions.

The researcher, as moderator, was attentive to the group interactions that allowed him to observe and understand the agreement or disagreement between participants concerning the electricity and magnetism concepts. The discussions were open-ended to yield additional alternative conceptions and conceptual knowledge for strengthening the data obtained with the modified DEEM and concept maps. To this end, the participants' discussions were audio-taped.

3.4.4 Concept Maps

Concept maps (CM) formations in the selected conceptual areas of electricity and magnetism were another empirical data source of this study. As a research tool, concept maps were used to visualize the individual student's conceptions in terms of their graphic representation or organization and consequently evaluate their conceptual change of electricity and magnetism concepts.

The students were asked to construct concept maps before and after intervention. They were told to take 'electricity and magnetism' as core (central) concept for their concept maps. Correspondingly, list of concepts from the selected two conceptual areas were provided to them in referring to the widely used standard textbooks for the course (Appendix C). In addition to the concepts provided, the students were allowed to add more related concepts (if they had some) to their own concept maps.

Before the creation of their actual concept maps, participants in both control and experimental groups were given a training of 4 hours on the construction of concept maps. The contents of the training were focused on examining the purpose of concept maps, sharing examples of concept maps and a description of how to construct concept maps (Miller et al., 2009). During the training, concepts used as example in the concept maps were not from the electricity and magnetism concepts in order not to influence the scores in their actual concept maps.

3.5 Ethical Considerations

Concerning ethical issues, the research participants were treated as autonomous individuals whose decisions on whether or not to participate were respected. The participants' permission was requested along with the department's support before data collection commenced. The students were informed that the research test scores were confidential and would have no impact on their classroom assessment. They were informed that the research test scores and any other means of data collection were confidential and will have no impact on their classroom assessment. In addition, written consents were given by the participants (see Appendix D).

Moreover, as per the requirement of the Institute for Science and Technology Education at UNISA, a student conducting research as part of his/her study must seek ethical clearance from the University's Ethical Review Committee. Accordingly, a request for ethical clearance was made and approval was granted (see Appendix E).

After the treatments process was completed and all the post data collections were done, the intervention process was reversed for two sessions to make an effort of balancing the knowledge gained by the students in both experimental and control groups.

3.6 Issues of Trustworthiness

Efforts were made to address trustworthiness of the data collection methods in this study. Thus, the issues of the validity (the degree to which a method/instrument measures what it purports to measure) and the reliability (the consistency with which it measures it over time) were addressed as described in the following subsections.

3.6.1 Validity and Reliability of the Diagnostic Tests

The validity and reliability of the CSEM as a research tool was shown by (Maloney et al., 2001; Planinic, 2006) for a broad conceptual survey of students' knowledge bases in electricity and magnetism conceptual areas. However, a pilot test was conducted and the face and content validity of the test were verified by three experienced lecturers of the field in the Department of Physics at Ambo University. In other words, they were asked to ensure that the essential conceptual areas of electricity and magnetism were covered in the items so that the test is valid for the survey of concepts of electricity and magnetism. In addition, the reliability of the test was checked using the Kuder Richardson-21 estimation (KR-21= 0.86), which was an acceptable value for both individual and group testing (Ding & Beichner, 2009).

With regards to the DEEM, although Marx (1998) had checked its validity and reliability as a research tool a pilot test was conducted to contextualize the test items and then assure validity and reliability of the modified DEEM version for this particular context. To this end, the face and content validity of this test was also checked by three experienced lecturers of the field in the Department of Physics. The test items are short which most of them are accompanied with self explanatory figures. As result, they are found easy to understand by the students. This was checked during the pilot test that no student complained about interpreting the items because of their English knowledge. In addition, the KR-21 estimation of the test was calculated as 0.87 which was acceptable value for both individual and group testing.

3.6.2 Validity and Reliability of Focus Group Discussions

For validity of focus groups discussion, the factual fitness of the participants' discussion was checked (not to omit and/or incorrectly transcribe). With regards to its reliability a guide for focus groups formation and discussion was developed for implementation and replication of the discussions.

3.6.2.1 Focus Groups Formation and Discussion Guide

Focus groups formation and discussion guide was developed to keep consistency of the discussions among the focus groups and help other researchers who need to undertake similar investigations or who need to replicate the study in a similar or other context. The guide incorporates the selection methods of the participants, the number and size of the groups, the type and number of discussion questions, the time schedule and the moderator's background in relation to the domain of the study.

Selection Method of Participants: Students were asked to participate voluntarily in the focus group discussions. Each focus group was homogeneous with regard to their scores in the CSEM test to minimize influences of possible dominant students during the discussions. To this end, the following activities were sequentially done.

First, the CSEM test was administered to all the participants and their scores' mean and median were described. The mean and median scores of the students were 20.8% and 21.9%, respectively (See Table B1 in Appendix B). Next, the students were divided into four groups using their median score. In this division, each laboratory class for the course was made to have one focus group of students who scored above the median and another focus group of students who scored below the median (See Table B2 in Appendix B). The students in the control and experimental groups were coded as CC and CP groups, respectively.

The number and size of the groups: Initially, 45 students who were registered for the course EM agreed to participate in this study. Accordingly, four focus groups, each with 11 to 12 students, were formed on the basis of their score in the CSEM test (See Table B2 & B3 in Appendix B). However, two to three students from each group were absent from the discussions which reduced the total number of participants to 35 with group size of 8 to 9 students each (See Table B4 in Appendix B). However, it was believed that the absence of two to three students from each group did not affect the result as their scores were found in the same level (See Tables B3& B7 in Appendix B) because the students' average score (20.8%) was found in the low random response state[2] (Bao & Reddish, 2001). From the participants, 98% of them scored below 31% and only one student (2% of them) scored 40.6%, the maximum score for the class (see Table B2 in Appendix B). This means that the students' scores found nearly in the low random response state. Therefore, it was noticed that the students' conceptual knowledge was in

[2] The random response state is a low-level response state in which the students' responses are somewhat evenly distributed among more than three choices.

the same low-level that their dominance on each other during discussions was assumed insignificant.

In addition, the homogeneity of the students in terms of their scores in the focus groups was shown by the pair wise comparison tests before and after attrition of some students. In other words, the mean scores of the formed four focus groups were compared by using ANOVA with pair comparisons to check whether they had significant differences. As a result, no statistical differences were found between the means scores of students in the two focus groups (CC1 & CP1) who scored above the median as well as the two groups (CC2 & CP2) who scored below the median (See Tables B5 & B6 in Appendix B).

The moderator: In this study, the moderator was the researcher himself, who has more than 20 years experience of teaching physics in both high school and university. The reason the researcher and moderator was the same person was due to the nature of the study. That is, conceptual change research needs knowledge of subject matter (knowledge of concepts of electricity and magnetism), knowledge of students' conceptions in the field and knowledge of theories of conceptual change. All these need a moderator who has done extensive review of literature in study area which was very rare case in the context of my county. Hence, it was believed that the moderator has the necessary subject matter knowledge, which is essential in relation to alternative conceptions and conceptual change research.

The type and number of discussion questions: Nine open-ended conceptual questions from the concepts of EPE and EMI (see Appendix F) were prepared for discussion. The number of questions was corresponding to the minimum number of concepts and relationship between concepts intended to measure the students' conceptual understanding in the two conceptual areas. Accordingly, the questions in the conceptual areas of EPE were related to the concepts of electric potential, electric potential energy, relationship between electric potential and electric field and relationship between electric potential and electric potential energy. Similarly, the questions in the conceptual areas of EMI were associated to the concepts of electromagnetic induction (general question), magnetic flux, ways of producing induced emf and/or induced current, relationship between induced current and induced emf, the concept of Faraday's Law of induction (see Appendix F).

Every member of the group was expected to participate actively in the discussions. The first round of discussion (before intervention) were held before the semester's classroom learning commenced and was used to record their preconceptions. The second round of discussion was held after intervention, two months later after the first round of discussion. This was used to record the shift of their conceptions (if any). Both pre and post intervention discussions lasted until ideas of the participants were exhausted and no additional and new EPE and EMI conceptions were made.

The time schedule: The maximum time allocated for the discussion of each group was approximately 2 hours. However, each group's discussion was almost finished within 90 minutes on the nine discussion questions of the two conceptual areas.

3.6.3 Validity and Reliability of Concept Maps

According to McClure et al. (1999), the validity of decisions made using information from concept maps assessment are influenced by both the nature of the question and evaluation of concept maps. Thus, the concept maps task was used to reflect on the content of electricity and magnetism concepts intervened (see Appendix C).

According to Mistades (2009), the reliability of concept maps is interpreted as the consistency of the scores on the various concepts given to students. To this end, the researcher and one senior lecturer in the field were used as raters. The lecturer was orientated with regards to the evaluation procedure. The two raters independently scored randomly selected CM of students before the actual scoring. The raters' agreement on the scores was compared for an estimation of inter-rater reliability. As a result, the scores were correlated and the inter-rater reliability estimate was 0.71, which was a reasonable result.

3.6.4 Assumptions and Mechanisms for Reducing Contamination Threat

Contamination is defined as the process whereby an intervention intended for members of one group of a study is received by members of another group (Howe, Keogh-Brown, Miles & Bachmann, 2007). In short, it is the sharing of information among the treatment groups.

Therefore, contamination or diffusion can be categorized under the transmission model of information sharing.

3.6.4.1 Assumptions

Diffusion is most likely to occur when an intervention is perceived as beneficial. For example, if the outcome of the process of intervention is included in a classroom examination for grading, it would be eagerly and frequently discussed outside the classroom between the students of the two groups, which was not the case in this study. In addition, simple interventions like recalling or recognition of information which are obvious to the members of the different groups are most likely to lead to contamination.

Complex and multifaceted interventions, on the other hand, are less prone to contamination because they cannot easily be transferred from one participant to another (Howe et al., 2007; Keogh-Brown et al., 2007). Alternative conception, for instance, is very stable and cannot be removed by simple transmission of information or by the transmission model of learning. Thus, conceptual change is a complex process that needs insight and intervention (Planinic, 2007), and cannot be effected through information sharing between students by itself (Baser &Gerban, 2007; Dykstra et al., 1992; Hake, 1998). Thus, conceptual change learning that involves the transformation of alternative conceptions into scientific conceptions on the bases of the constructivist learning model cannot be attained simply by students' information sharing (transmission model of learning). Although students may share information after the class, they cannot repeat the conceptual change learning environment provided in the class. Hence, negligible error due to interference of data was assumed.

3.6.4.2 Mechanisms

In this study, the students were not aware to which class they were allocated; either the CCS or CPS class. The conceptual topics presented to both groups of students and the simulations used during the treatments were the same. Also, the way the students were grouped in each class in order to share computers were similar. The students were interested in the simulations and indicated that the simulations helped them in their learning. Also, they considered themselves fortunate as they were taught by using only computer simulations. As a result, the students' discussions outside the class were possibly about the simulations and not about the concepts. This means that the design of the interventions was imperceptible for contamination.

Classical conceptual change has limitations for students learning of complex concepts (Duit & Treagust, 2003; Li et al., 2006). The support provided by the teacher (the cognitive perturbation) was done at appropriate junctures during the learning process in the classroom. This support varied from group to group, based on their contextual needs within the experimental class. Thus, it was believed that simple arbitrarily talk of the students to each other about the concepts or their sharing of information outside the classroom had an insignificant effect on the treatments. This was so because initiation of the supportive approaches was done by the teacher and its implementation outside the class by the students was believed to be impractical.

Therefore, based on assumptions proposed and the efforts made, it was believed that contamination had an insignificant effect on the students' conceptual change.

3.7 Methods of Data Analyses

In this study, data collected by CSEM was quantitative analyzed first because of the need to use the students' scores in the test for the formation of focus groups for all the participants. Then, the analyses of data from FGD, CM and modified DEEM were independently done both before and after interventions. The data collected by the focus groups discussions were qualitatively analyzed, while the data collected by the means of students' concept maps were analyzed both qualitatively and quantitatively. The data collected by the modified DEEM were analyzed quantitatively.

The qualitative analyses of FGD and CM data were done to answer the first and the second research questions, while the quantitative analyses of data collected by the modified DEEM and students' concept maps were done to answer the third research question. In addition, the results of the quantitative analyses of both concept maps and the modified DEEM data supplemented that of the qualitative analyses. Moreover, qualitative analyses results helped to understand and explain the quantitative results.

3.7.1 Qualitative Analyses: Framework Thematic Analyses of Focus Groups Discussions and Concept Maps Data

The framework analysis method (Rabiee, 2004; Ritchie & Spencer, 1994) was independently adapted for focus groups discussions and concept maps qualitative data analyses. The specific reason for adapting this method was its characteristic feature that allows themes to develop both from the literature and from the discussion or depiction of the research participants (Rabiee, 2004). In addition, the diagnosed categories or themes of the students' conceptions were considered as structure or framework of their understanding in the context of the study. Consequently, in the analyses, the categories of students' conceptions discussed in the literature review were considered to develop the framework themes of conceptions. Besides, there was an open-mindedness to include additional emerging themes from the discussions of the students. Thus, five-stages of the framework analysis described by Ritchie and Spencer (1994) were used as the basis for the focus groups discussions and concept maps data analyses. These were familiarization, identifying a thematic framework, coding, charting and interpretation.

3.7.1.1 Familiarization

For the focus groups discussion data, the audio-taped interviews were transcribed verbatim and complemented with observation notes. Repeated listening to tapes and reading the observational notes were done to understand a sense of the entire discussions. In short, a systematic review of observational notes and transcripts were conducted at this level. Similarly, for the concept maps data, individual student's concept maps was transcribed into statements. Repeated reading of the transcriptions was made to have a broad overview of all the ideas of the students' depictions before categorizing them into themes.

3.7.1.2 Identifying a Thematic Framework

In this stage, for the two sources of qualitative data, the predetermined themes were identified and additional themes were developed in accordance with the conceptions expressed by the students. Simultaneously, the conceptions of the students were filtered and classified (categorized) into themes. Filtering, in this case, was meant to keep aside the irrelevant participants' statements, which were irrelevant to the research question.

Regarding the concept maps data, the bases for the thematic framework were the conceptions expressed by the students. It means that the valid (relevant) and invalid (inappropriate) responses that appeared on every student's CM as propositions, hierarchies, cross-links and examples were used in the organization of the themes. Then, the transcribed statements generated from each student CM were classified into alternative conceptions and conceptual knowledge. In other words, the valid or relevant statements of students were categorized as conceptual knowledge, while their invalid or inappropriate statements were categorized into the alternative conceptions. Furthermore, both parts of the students' conceptions (alternative conceptions and conceptual knowledge) were categorized based on the ways they were represented or described by the students.

In this part of the framework analysis, for both FGD and CM data, open-mindedness was maintained so as not to force the data to fit with the predetermined themes. Consequently, in addition to the predetermined themes, extra themes were categorized. The extra themes were meant for those students' ideas that did not fit into the preset themes. These additional themes were labeled as *mixed conceptions* and *loose ideas*. The additional conceptions were the students' incorrect descriptions of concepts that possibly could be categorized into more than one predetermined category, while the loose ideas were incorrect descriptions of the students that could not be categorized into one or more categories. Therefore, in this iterative process, a framework of students' conceptions were developed and structured from both the preset and the emergent categories of the students' conceptions.

3.7.1.3 Coding

This third stage was applied to all the transcribed data that correspond to particular themes (categories). At this stage, for the data extracted with FGD, segments of transcripts were independently coded in terms of the categories they belonged to with their respective focus groups. For example, a segment of the transcripts of data that belonged to naïve physics and which was discussed by the first focus group was coded as NPFG1. Likewise, a segment of transcript that belonged to lateral alternative conception and which was discussed by the second focus group was coded as LACFG2 and so on.

Similarly, segments of the transcripts of students' concept maps data were coded in terms of the categories they belonged to with the corresponding students (coded identifications) discussed the segments. For example, a segment of the transcribed data a student (say, code S01) described and belonged to naïve physics category was coded as NPS01. In both FGD and CM data analyses, the codes were annotated at the margins beside the texts.

3.7.1.4 Charting

In this fourth stage of the analysis, the specific pieces of data that were coded in the previous stage were arranged in tables of the themes (categories of students' conceptions). Firstly, the coded segments of the transcribed data were organized into categories in relation to the concepts in the discussion questions. In other words, coded descriptive statements of the students' conceptions in EPE and EMI concepts were set into categories. Then the data were shifted from their original textual context and illustrated in tables that consist of headings and subheadings that were drawn during the thematic framework.

3.7.1.5 Interpretation

This fifth and last stage involved the analysis of key characteristics of students' conceptions in the categories that were presented in tables. This analysis was able to provide tables of the data set. In short, interpretations were done on the developed categories or the framework in terms of frequency, extensiveness, consistency/inconsistency (Rabiee, 2004) and distribution of the students' conceptions within and across the categories. These key characteristics were analyzed as follows.

i. *Frequency and Extensiveness:* The term frequency (f) relates to the consideration of how often a conception or an idea was made within the participants (in the case of individual data collected with CM) or across focus groups discussions (in the case of group data collected with FGD), while the term extensiveness refers to the total frequency of the conceptions in a category.

   In the case of FGD data, the frequencies of students' conceptions discussed across the four focus groups were analyzed. In other words, this frequency was the same as the number of focus groups independently discussed a conception. The maximum of this frequency of a conception was four, which is equal to the number of the focus groups, while its minimum was one, i.e., when only one focus group discussed a conception. Correspondingly, the total frequency (extensiveness) was analyzed in each category of students' conceptions. The extensiveness was analyzed to study how often the students' conceptions were found in the categories. The frequency and extensiveness of the conceptions in each category were provided by tables in the results section to guide the interpretation.

In the case of CM data, the term frequency (f) relates to the consideration of how often a conception or an idea was depicted within the participants. The maximum frequency of a conception would be equal to the number of participants involved in the concept maps. Correspondingly, the total frequency was equal to the total number of students described conceptions in a category. It was analyzed to study the extensiveness of the students' conceptions in the category. Thus, the *extensiveness* referred to the total number of the students who described the conceptions in a category. Also in this analysis, both the frequency and the extensiveness of students' conceptions in categories were provided in the tables to guide the interpretations of the results.

ii. *Consistency or Inconsistency*: Consistency/inconsistency was considered as the changes or the variations in conceptions of a concept by the students within and across the categories. The consistency/inconsistency of the students' alternative conceptions was presented in a table in the results section to guide the interpretation.

iii. *Distribution:* Distribution referred to the total number of alternative conceptions in a category of students' conceptions. Correspondingly, percentage distribution referred to the percentage of the ratio of the number of conceptions in a category to the total number of conceptions and ideas in all the categories.

3.7.2 Quantitative Analyses

3.7.2.1 Concentration Analysis of Data Collected with the Modified Diagnostic Exam of Electricity and Magnetism

Concentration analysis is a new statistical approach developed by Bao and Redish (2001) in order to analyze the number of alternative conceptions used in students' responses to multiple-choice tests. In addition, the analysis is used to investigate the degree of relative importance of the alternative states/models of students' responses in a given population. Consequently, the fundamental nature of this analysis is its ability to find patterns in the students' alternative conceptions and conceptual knowledge. In other words, if students consistently choose distracters that represent particular alternative conceptions, then some conclusion on the students' conceptions of physics concept can be made.

Accordingly, in this approach, every item of a diagnostic test is mainly represented by two parameters, the concentration score (S) and concentration factor (C_f). The concentration score is the fraction of number of students' correct answer to each multiple-choice question. It is expressed as:

$$S = \frac{n_c}{N} \qquad \text{eq. (1)}$$

In the equation, n_c stands for the number of correct answers to an item and N is the total number of items. Its values vary from 0 to 1.

The concentration factor (Bao & Redish) is the concentration of the students' responses to the different options of each item. It could be expressed as:

$$C_f = \frac{\sqrt{m}}{\sqrt{m}-1}\left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2}}{N} - \frac{1}{\sqrt{m}}\right). \qquad \text{eq. (2)}$$

In the equation, *m* stands for the number of multiple options and n_i is the number of students' responses to the i^{th} option, where *i* varies from 1 to *m* and N is the total number of items of a test. The values of concentration factor also vary from 0 to 1.

In addition, Bao & Redish introduced concentration deviation (C_d), the concentration of students' alternative conceptions. The concentration deviation formula is given as:

$$C_d = \frac{\sqrt{m-1}}{\sqrt{m-1}-1}\left(\frac{\sqrt{\sum_{i=1}^{m} n_i^{\,2} - n_s^{\,2}}}{(N-n_s)} - \frac{1}{\sqrt{m-1}}\right). \qquad \text{eq. (3)}$$

In this case, n_s stands for the number of students' responses to the correct answer and all the notations in this equation are also the same as that of the concentration factor.

Therefore, students' responses to the modified DEEM were analyzed using concentration analysis (Bao & Redish, 2001). This means that the concentration of alternative conceptions and conceptual knowledge were analyzed before and after the intervention in terms of concentration factors [0, 1] and concentration scores [0, 1]. In addition, concentration deviation (the concentration of alternative conceptions), as in Bao & Redish, was analyzed before and after intervention to see the shift or change in students' conceptions. Moreover, the concentration factor and the concentration deviation were compared using paired samples t-test in order to determine whether the students' responses were consistent or not in the DEEM test.

Students' Model States: Another important part of the concentration analysis is the characterization and categorization of students' model states. For its realization, the students' response patterns were formed by combining their response concentration scores with their response concentration factors and concentration deviations. Then three-levels coding (Bao & Redish, 2001) were used to categorize students' response states (see Table 3.2).

Table 3. 2: Three-level students' model states categorization

Concentration Score (S)	Concentration factor (Cf)	Concentration deviation (Cd)	Levels
0 ≤ C< 0.4	0 ≤ C< 0.2	0 ≤ C< 0.2	Low (L)
0.4 ≤ C< 0.7	0.2 ≤ C< 0.5	0.2 ≤ C< 0.5	Medium (M)
0.7 ≤ C≤ 1.0	0.5 ≤ C≤ 1.0	0.5 ≤ C≤ 1.0	High (H)

This combination helped to code the concentration score and concentration factor that provide the student response patterns for each conceptual multiple-choice question. For this purpose, the possible students' model states categorization was done by combining concentration scores with concentration factors and concentration deviation deviations (see Table 3.3).

Table 3. 3: Students' possible model states categorization

One model state (Pure state)	HH	One correct model
	LH	One dominant incorrect model
Two models state	LM	Two possible incorrect models
	MM	Two popular models
	ML	Two non popular models
	MH	Two non popular models
Null model state	LL	Near random situation

Consequently, the students' response patterns (during both pre and post intervention) were formed by combining the response concentration factors with the response scores. The combination helped to code for the score and concentration factor that provided the student response patterns for each conceptual multiple-choice question.

3.7.2.2 Quantitative Analysis of Data Collected with Concept Maps

The propositions, hierarchies, cross-links and examples that appeared on every participant's CM were scored quantitatively before and after the intervention. A scoring rubric (McClure et al., 1999; Miller et al., 2009) adapted from outline of Novak and Gowin (1984) and protocol of Shaka and Bitner (1996) (see Appendix G). The scoring was done by involving all the elements of concept maps that appeared on every participant's mapping as propositions, hierarchies, cross-links and examples (see paragraph 4 in Section 2.4.6). In the scoring rubric, students' representations or descriptions of concepts in terms of the four elements were categorized into five levels that were scored from zero to four (see Appendix G).

3.7.2.3 Analysis of Covariance

Analysis of covariance was used on both quantitative data which were collected by the modified DEEM test and the students' CM in order to triangulate the results. ANCOVA was used to determine if there was a significant difference between the treatments on the modified DEEM post-test scores, with pre-test scores as covariate. Likewise, the difference between the averages of post CM scores of both treatment classes were analyzed using ANCOVA with pre CM scores as covariate and to examine the effectiveness of the CPS in comparison with the CCS.

3.7.2.4 Average Normalized Gain

The average normalized gain <g> is the average *actual* gain [<%post> - <%pre>] divided by the *maximum possible average gain* [100% - <%pre>], where the angle brackets indicate the class averages (Hake, 1998). To characterize and compare students' conceptual change of both treatment groups, Hake's average normalized gains of the two quantitative data (the modified DEEM and the CM) from pre to post scores were analyzed

Physics education researchers characterize normalized change (<g>) (Hake, 1998) of students' scores in survey of conceptual tests as: <g> ≥ 0.7- High, 0.3 < <g> < 0.7 - Medium and <g> < 0.3 - low. Hence, in this study, these three levels categorization of average normalized gain was used to characterize students' conceptual change.

3.8 Procedures for Treatments of the two Classes: Cognitive Conflict using Simulations and Cognitive Perturbation using Simulations

Though the supportive approaches for both CCS and CPS classes were different, the same content was taught to both classes by the same instructor (researcher). The content taught was based on their alternative conceptions and conceptual knowledge identified in the two conceptual areas selected for the study before intervention.

Students have basic computer literacy from their high school education. Also, they took one general computer course in the first semester before the intervention. In their first session before treatment (2hrs), all the students were instructed how to use interactive simulation software. Following the instruction, students in both control and experimental classes were divided into four groups each, comprising five to six students per group. The way the students were grouped in order to share computers were similar for both classes. Each group was assigned to a computer and was required to use interactive physics simulations selected to suit the conceptual areas of electricity and magnetism meant for the study. Then, both control and experimental classes were separately treated for two sessions per week (the duration of each session was two hours) for two consecutive weeks.

3.8.1 Characteristics of the Selected Simulations

The same interactive simulations were chosen for both treatment classes (the CPS and CCS classes), to support the students' learning in the concepts of electric potential and energy and electromagnetic induction. As mentioned in Section 2.4.5, these simulations were selected from the PhET website http://PhET.colorado.edu online free distribution. The basis for their selection was the contents of the concepts selected for this study. In short, the simulations were believed to support and make students interactive in their learning of the selected concepts for this study. The selected simulations for EPE and EMI concepts were *Charges and Fields* (see Figure 3.1) and *Faraday's Electromagnetic Lab* (see Figure 3.2), respectively.

3.8.1.1 Charges and Fields Simulation and Its Characteristics

In this simulation, the students were guided to measure electric potentials of positive and negative point charges, run electric field lines and equipotential lines, measure electric potentials and electric fields using simulated *voltage reader (potential tool)* and *field sensor*, respectively. The students can place and move point charges around on the *playing field* and then view the electric field, electric potential and equipotential lines (See Figure 3.1).

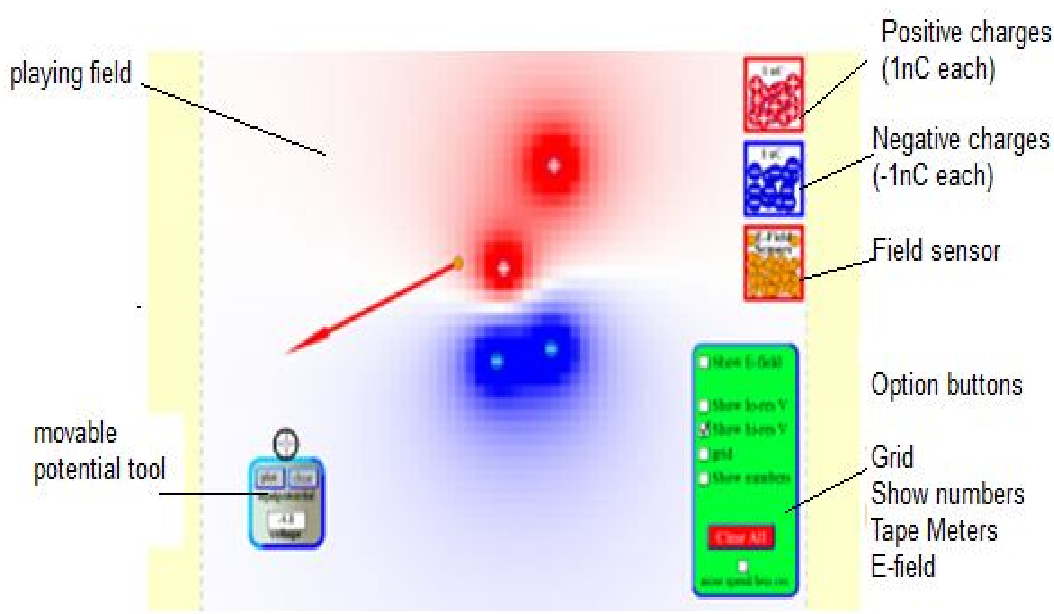

Figure 3. 1: The Charges and Fields Interactive Simulation

The simulation is interactive that can be easily adjusted to move and put any kind and amount of charge at a point or different points needed (using a computer mouse), measure electric potentials and plot equipotential lines (using the *voltage reader* or *potential tool*) and indicate the direction of electric fields at different points in the field (using the *field sensor*). In addition, the option buttons: *grid, show numbers* and *tape meters* are used to display exact location of charges and measure the values of electric potential and electric field at different points point in the *playing field* (see Figure 3.1). The students played around the playing field and discussed on the outputs of the interactive simulations.

3.8.1.2 The Faraday's Electromagnetic Lab Simulation and Its Characteristics

This application software has been used as series of four simulation panels. These panels are *bar magnet*, *bar magnet with a coil* and *electromagnet*, *transformer* and *generator*.

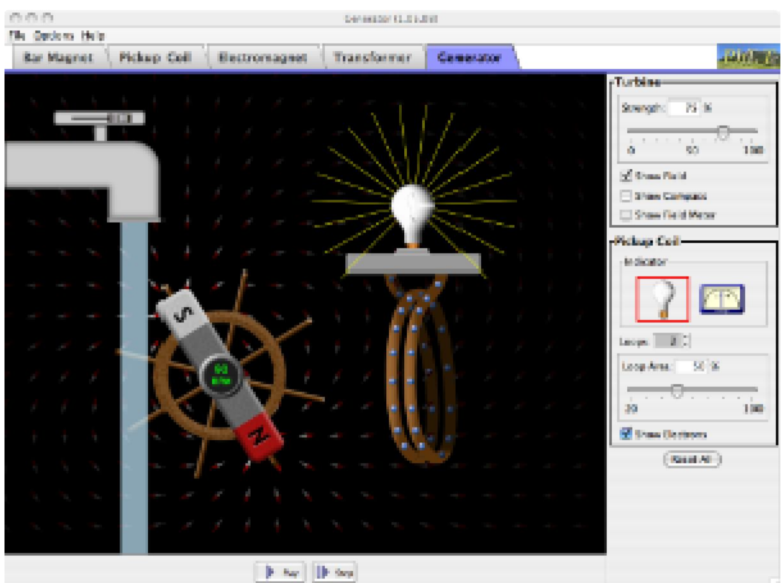

Figure 3. 2: The Faraday's Electromagnetic Lab[3]

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[3] This simulation has a series of panels in which students can explore bar magnets and electromagnets, induced currents/induced emf, transformers and then hydroelectric power generation.

All parts of this Electromagnetic Lab simulation panels have common different operating options which help to: *show field*, *show compass*, *show field meter and change magnetic field strength*. In addition, except the *bar magnet* panel, all of the panels have operating options that help to change *number of loops* and *loop area*. Besides, a *bulb* or a *voltmeter* option is used as indicator for induced electromotive force. Moreover, the direction of flow of electrons in the loops can be shown while the emf is induced. The *field meter* is a movable interactive part that is used to detect magnetic field strength at different points in the field region. It can also detect variation of magnetic field at a point. Thus, the simulation is highly interactive that allows the students to do tasks in reaction to their actions.

3.8.2 Cognitive Conflict with Simulations Class

The cognitive conflict strategy was used with selected physics interactive simulations for the learning of students in the control group. The simulations suited the conceptual areas for intervention. The identified alternative conceptions were presented under the topic of a session or a conceptual area. This means that the students' existing ideas about the concepts under intervention were made explicit and were then directly challenged. The intention was to create cognitive conflict in the students and to make them dissatisfied with their alternative conceptions and to increase the status of scientific conceptions. With this in mind, the researcher requested the students, prior to their interaction with the simulations to present their predictions of the outcomes based on their existing ideas. After they had had the opportunity to do the simulations the students realized that the outcomes turned out to be different from their initial predictions. This discrepancy between predictions and outcomes created cognitive conflict in the students because the discrepant events provided contradicted the students' alternative conceptions and invoked cognitive conflict (Hewson & Hewson, 1984; Baser, 2006). In trying to resolve this conflict, the researcher guided the students to abandon their alternative conceptions and replace them with the scientific conceptions. In doing so, the conditions for the classical conceptual change model, namely *dissatisfaction, intelligibility*, *plausibility* and *fruitfulness* (Posner et al., 1982) were followed to guide students' learning and to evaluate the level of their conceptual understanding (see Appendix H).

3.8.3 Cognitive Perturbation with Simulations Class

In the experimental class there were various reasons for using cognitive perturbation with interactive simulations as a supportive intervention. Firstly it was supposed to reduce the number of students who failed to change their alternative conceptions. This was done by supporting them gradually, by posing cognitive perturbation, to move step by step from their preconceptions towards scientific conceptions. This provision of cognitive perturbation by the researcher was based on the status of the students' explanations of the simulations. In addition, the students were constantly challenged by the researcher with questions which were based on their explanations of concepts in the EM interactive simulations. This was due to the contention that cognitive perturbation would help the students' learning towards the forming of intermediate and more scientific conceptions than their preconceptions. The second reason was the lack of sensitivity of the cognitive conflict approach towards non-cognitive elements and social contexts (Li et al., 2006). To overcome this limitation, the learning situation in the classroom setting was designed to provide for both individual and social involvement of students. For this purpose the researcher provided pedagogical social support and cognitive perturbations to students in addition to the student-student interactions in groups. However, he did not provide the students with immediate solutions or direct them to follow a predetermined path of learning during the interaction with the simulations. Hence, the researcher's facilitation was focused on working with rather than against the students' alternative conceptions in the process of their learning with the help of the interactive simulations.

Unlike in the CCS class, the students in the CPS class were not asked to predict the outcomes of the simulations. The students' conceptions of EM concepts were supposed to be inconsistently diversified. In addition, their conceptual knowledge was so low that they lacked conceptual resources (capacities) to engage themselves in the classroom interaction. Thus, instead of attempting to set the students of the CPS class into cognitive conflict, the researcher used a mechanism of gradually supporting their learning by providing cognitive perturbation at appropriate junctures. Accordingly, the tasks that all the groups of students performed with the help of interactive physics simulations were made to have three phases: the undertaking phase, the presentation phase and the refining phase (see Appendix I).

In the undertaking phase, the students were asked to run the simulation and do the task given to them in groups. In this part, each group of students was given the chance to discuss (student-student discussion) the tasks they performed in the interactive simulations.

In the presentation phase, the students reflected on their understanding of the concepts. During the students' reflections, the researcher valued their ideas to motivate them in their progressive learning. This phase was found to be an appropriate situation to notice their learning (understanding) gap and then provide them cognitive perturbation based on their contextual difficulties to support their learning towards the intended scientific conception. In this study, it was mostly given in the form of a question and was believed to rectify the students' misunderstanding.

In the *refining part*, the students were expected to incorporate the teacher's comments and use the cognitive perturbations as a scaffold in their construction of conceptual knowledge towards the scientific conceptions.

Therefore, the CCS and the CPS classes differed only in the support the researcher was offering: the cognitive conflict strategy for the CCS class and the cognitive perturbation strategy for the CPS class.

3.9 Summary of the Chapter

This chapter described the research methodology which involves the research design, research sample, instruments, ethical considerations, issues of trustworthiness (validity and reliability of the instruments) and methods of data analyses (framework thematic analysis, concentration analysis, analysis of covariance and average normalized gain) and treatment procedures.

Due to the nature of the study of conceptual change which is a very complex and gradual ongoing learning process, this case study employed a *quasi-experimental design* and used *concurrent mixed methods* research in which the results were merged at the point of interpretation. Naturally existing two lab groups for the course were randomly assigned into CCS and CPS classes. Data collection instruments were the Modified DEEM, FGD and CM. Validity and reliability of the test were estimated using experts' consensus and Kuder

Richardson-21statistical estimation, respectively. For validity of FGD, the factual fitness of the participants' discussion was checked. For its reliability, a guide was developed for implementation and replication of the discussions. The concept maps task was used to reflect on the content of EM concepts intervened for its validity and raters' agreement on the scores was compared for an estimation of inter-rater reliability. In addition, assumptions were proposed and efforts were done to minimize contamination effect. Data from FGD and CM in pre and post intervention were analyzed qualitatively using framework thematic analysis to answer the first and the second research questions while data from the modified DEEM and CM in pre and post intervention were analyzed quantitatively using concentration analysis, ANCOVA and also average normalized gain to answer the third research question.

CHAPTER 4

PRE INTERVENTION RESULTS

In this chapter, the qualitative and quantitative results of the pre-intervention study are presented and discussed. These pre-intervention study mainly provided results to answer the first research question. Baseline data are needed in order to answer the second and third research questions. These baseline results will be used to compare the students' conceptual changes after the intervention.

PART I: QUALITATIVE RESULTS

In this part, the results to the first research question namely 'What are the categories of students' conceptions in the electric potential and energy (EPE) and electromagnetic induction (EMI) conceptual areas before intervention?' were analyzed. In order to answer this question, the results of the pre intervention data from focus groups discussions and concept maps of the students who participated in the study were presented and discussed. G*roup-based data* analysis was used to analyze data from the focus groups discussions while *individual-based data* analysis was used when analyzing the concept maps. Both analyses were independently done using the framework thematic analysis step by step starting from the first stage of familiarization to the last stage of interpretation (see Section 3.7.1). The transcribed and coded data were then categorized into categories (themes) of students' alternative conceptions and conceptual knowledge.

4.1 Qualitative Results of Focus Groups Discussions Data

In the pre intervention results of the group-based data from the four focus groups, six categories of alternative conceptions and two categories of students' conceptual knowledge were identified. Among the categories of alternative conceptions, four were the presupposed categories based on the literature review namely naive physics, the lateral alternative conceptions, the ontological alternative conceptions and the Ohm's p-primes while the other two that emerged were termed mixed conceptions and loose ideas. The two categories of students' conceptual knowledge were diagnosed as *hierarchical* and *relational* conceptual knowledge (see Section 2.3.2).

4.1.1 Categories of Students' Alternative Conceptions

4.1.1.1 Category1: Naïve Physics

Naive physics is defined as a simplified and less organized students' theoretical view of a concept (see paragraph 5 in Section 2.3.1).

Naïve Physics in the Concepts of EPE

The students' alternative conceptions of the concepts of EPE were categorized into the naïve physics in relation to their frequency and extensiveness (see Table 4.1). As illustrated in the Table, from the 17 alternative conceptions categorized to the naïve physics, eleven were discussed only once by any one of the focus groups and six were discussed only twice by any two of the focus groups. However, there were no naïve physics discussed by more than two focus groups in this case.

The alternative conceptions were further categorized in terms of electric potential, electric field, and electric potential energy (see Table 4.1). From these alternative conceptions, seven were in electric potential, four in electric field and six in the energy concepts. For example, from electric potential, two of the focus groups described that there is an electric potential only when a charge is at rest and they considered the potential difference as the difference between only positive and negative potentials. Also, they perceived that electric potential of two opposite charges separated by some distance is zero. This statement would be true if the two opposite charges are equal and the potential is calculated at their midpoint. From electric field concept, another example was that of uniform electric field implies a uniform velocity. The students considered that a charge released in a uniform electric field moves at a constant velocity. This was a consequence of "force implies velocity" from Aristotelian physics. This means, the students had some intuitive reasons for their explanation of uniform electric field implies a uniform velocity. However, they were unable to visualize that the electric field can change the velocity of a moving body or consequently, it can accelerate a charged particle released in it. From the energy concept, kinetic and potential energies are constant in electric field. In this case, two focus groups of students considered as if the two forms of a charge's energy are independently constant in an external electric field.

Table 4. 1: Pre intervention naïve physics in the concepts of EPE with their frequency and extensiveness

Concepts		Naïve physics in EPE concepts	Frequency
Electric potential	1.	Charge at rest implies electric potential.	2
	2.	Electric potential of two opposite charges system is zero.	2
	3.	Potential difference is the difference between positive and negative potentials.	2
	4.	The potential difference of charges separated by large distance is zero.	1
	5.	An electric potential is confined only in an atom.	1
	6.	Equipotential lines have only circular structure.	1
	7.	A changed body has only one type of charge	1
Electric field	8.	Positive charge is the only source of electric field.	2
	9.	Uniform electric field implies a uniform velocity of a charge.	2
	10.	In an electric field, positive charge accelerates but the negative charge decelerates.	1
	11.	Uniform electric field implies a projectile motion of a charge	1
Energy	12.	Kinetic energy of a charge is constant in a uniform electric field.	1
	13.	Kinetic and potential energies are constant in an electric field (naïve energy idea).	2
	14.	Positive charges have positive energy; negative charges have negative energy.	1
	15.	Work is done on an equipotential line.	1
	16.	Moving charges have no electric potential energy.	1
	17.	The kinetic energy of a charge changes on an equipotential line.	1
		Extensiveness of Naïve physics in EPE concepts	**23**

Naïve Physics in the Concepts of EMI

In the concepts of EMI, seven alternative conceptions were categorized into the naïve physics (see Table 4.2). From these alternative conceptions, three were in the magnetic field and magnetic flux and another three were in the induced current/emf concepts. For example, two focus groups of students described that induced current is implied by magnetic field. In this case, the students considered the presence of magnetic field as the cause for induced current. In general, the naïve physics in the EMI concepts were less extensive than those in the concepts of EPE (see Tables 4.1 & 4.2).

From the seven alternative conceptions depicted and categorized into naïve physics of EMI concepts, only two of them were discussed twice by two of the focus groups, while the other five were discussed only once (see Table 4.2). However, in a similar way to the naive physics of EPE concepts, there were no naïve physics of EMI concepts discussed by more than two focus groups.

Table 4. 2: Pre intervention naïve physics in the concepts of EMI with their frequency and extensiveness

Concepts		Naïve physics in EMI concepts	Frequency
Magnetic field & Magnetic flux	1.	Normal unit vector to an area should be normal to the magnetic field to produce magnetic flux.	1
	2.	*Motion of a magnet as a cause for magnetic flux:* the magnetic flux is due to motion of a magnet through its field.	1
	3.	*Motion of a magnet accelerates charges*: motion of a magnet causes a force that accelerates or decelerates charged particles. (magnet pushes or pulls charged particles)	1
Induced emf/induce d current	4.	*Magnetic field implies induced current:* electromagnetic induction is the process of producing current using magnetic field.	2
	5.	*Magnet implies induced current*: electromagnetic induction is a process of producing or inducing current from a magnet.	2
	6.	*Presence of coils implies emf*: when one coil is placed near another coil, an induced electromotive force is produced.	1
	7.	*Constant current implies constant emf:* a constant current in one coil induces an emf in the other coil.	1
		Extensiveness of naïve physics in EMI concepts	**9**

4.1.1.2 Category 2: Lateral Alternative Conceptions

The lateral alternative conception is defined as a concept in a hierarchy of concepts that could be incorrectly categorized into different branches (see paragraph 7 in Section 2.3.1).

Lateral Alternative Conceptions in the Concepts of EPE

In the concepts of EPE, there were 14 lateral alternative conceptions identified (see Table 4.3). For example, three focus groups of students exclusively considered electric potential as a force. It means that they incorrectly labeled electric potential under some properties of force. Although electric potential and force can share some properties and they are found in the same ontological category; laterally, they belong to different sub categories.

Out of the 14 alternative conceptions in this conceptual area, eight were in the concept of electric potential, four were in the concept of electric potential energy and two were in the electric field concept (see Table 4.3). In addition, among the lateral alternative conceptions of the concepts in EPE, two of them were discussed three times, four of them were discussed twice and eight of them were discussed only once in the four groups (see Table 4.3). There were no lateral alternative conceptions discussed by all the focus groups.

Table 4. 3: Pre intervention lateral alternative conceptions in EPE concepts with their frequency and extensiveness

Concepts		Lateral Alternative Conceptions in EPE concepts	Frequency
Electric potential	1.	*Electric potential as a force:* electric potential is the attraction or repulsion of two charges.	3
	2.	*Electric potential as an attractive force:* electrostatic potential is a potential of positive and negative charged particles.	2
	3.	*Electric potential as potential energy:* electric potential is a potential energy that electric charges possess.	2
	4.	*Electric potential as kinetic energy:* electric potential is created by an electric field because of moving charges.	1
	5.	*Electric potential as a vector:* electric potential is a vector which is based on the signs (directions) of charges.	2
	6.	*Electric potential as charge flow/current:* electric potential is made up of flow of charges from negative to positive charged materials.	1
	7.	*Potential as position & potential difference as a distance:* potential difference is the distance between two equipotential lines.	1
	8.	*Equipotential lines as electric field lines:* equipotential lines are electric field lines that are equal and parallel to each other.	1
Electric field	9.	*Electric field as force:* electric field is the force on any test charge.	1
	10.	*Electric field as magnetic field*: electric field changes the direction of motion of charges	1
Electric potential energy	11.	*Electric energy as a force:* electric potential energy is a conservative force. Electric potential energy exists between two unlike charges (*electric potential energy implies attraction force*).	2
	12.	*Electric potential energy as a potential difference:* electric potential energy is the difference between electric potentials.	1
	13.	*Electric potential energy as kinetic energy:* electric potential energy is when charges are in motion- (motion implies energy).	3
	14.	*Electric potential energy as a vector:* electric potential energy is a vector that depends on the signs (+ or -) of charges.	1
		Extensiveness of lateral alternative conceptions in EPE concepts	**22**

Lateral Alternative Conceptions in the Concepts of EMI

In the concepts of EMI, 15 conceptions were developed into lateral alternative conceptions (see Table 4.4). Out of these conceptions seven were in the process of electromagnetic induction, two were in magnetic flux and six were in the induced current/emf concepts. Except for one alternative conception, all of these depicted lateral alternative conceptions occurred only once in the four focus groups discussions.

Table 4. 4: Pre intervention lateral alternative conceptions in EMI concepts with their frequency and extensiveness

Concepts	Lateral Alternative Conceptions in EMI Concepts	Frequency
Electromagnetic induction	1. Electromagnetic induction as a flow of charges by magnetic field: magnetic field produces potential difference that causes a flow of charges form one coil to another.	1
	2. Current as induction: the process of electromagnetic induction takes place when a flow of charges produces current.	1
	3. Electromagnetic induction as a process of charging/charge transfer: to relate the current from one coil to the voltage in another coil, charges should move from one coil to another.	1
	4. Electromagnetic induction as a static charging process: induced current is produced by attracting electrons from materials.	1
	5. Electromagnetic induction as conduction current: electromagnetic induction occurs when an electromagnetic material is connected to non-electromagnetic material and causes flow of charges from one to another	1
	6. Charging by induction process as electromagnetic process: electromagnetic induction is charging a neutral body without connection	2
	7. Electromagnetic induction as a formation of electromagnet: electromagnetic induction means an electromagnet created without contact.	1
Magnetic flux	8. Magnetic flux as electric flux: magnetic flux means an electric field lines passing through an area.	1
	9. Magnetic flux as a magnetic field: -magnetic flux is magnetic field lines crossing a given electric field -an induced emf equals to flux multiplied by area over change of time	1
Induced emf/induced current	10. Induced emf as a potential difference: electrostatic force of charges produces electromotive force.	1
	11. Induced current as magnetic field: The cause for induced current is either a moving charge or a magnet.	1
	12. Induced emf as magnetic field: moving charge is a source for induced emf.	1
	13. Induced emf as a force**:** an exertion of electromotive force may cause induced current between the coils.	1
	14. Ampere's Law confusion with the Faraday's law: the relation between magnetic field and the induced current is that it is the induced current that produces magnetic field.	1
	15. Magnet as a charged object: in electromagnetic induction, electrons are induced from a magnet to uncharged object.	1
	Extensiveness of Lateral Alternative Conceptions in EMI concepts	**16**

4.1.1.3 Category 3: Ontological Alternative Conceptions

The ontological alternative conception is a concept which the students categorize it into incorrect ontological category (see paragraph 6 in Section 2.3.1). Students used some distinctive words for substance (or material object), like *connect*, *flow*, *move* and *release* to describe the EPE concepts.

In this theme, nine alternative conceptions were documented. Among these alternative conceptions, four were in the concept of electric potential, three were in the electric field concept and two were in the concept of electric potential energy. For example, the students considered electric potential, electric field and energy as substances (see Table 4.5). It means that they considered the concepts as an ontological nature of substance or matter. Among the nine ontological alternative conceptions, only two of them were discussed twice whereas the rest seven were discussed only once in the four focus groups.

This category of alternative conceptions was developed only in the concepts of EPE based on the data analyzed from the students' focus groups discussions. In other words, there was no students' alternative conception identified and categorized into ontological alternative conceptions category from the EMI concepts. The energy and force concepts are more familiar to the students in relation to material objects than the concepts in EMI, like induced emf. This made the students to conceive the ontological alternative conceptions only in the concepts of EPE.

Table 4. 5: Pre intervention ontological alternative conceptions in the concepts of EPE with their frequency and extensiveness

Concepts	**Ontological Alternative Conceptions in EPE concepts**	**Frequency**
Electric potential	1. *Electric potential as material object:* • positive potential is *connected* to positive charge; negative potential is *connected* to a negative charge • when electric potential is *released* charge is also *released*	2
	2. *Electric potential as charges*: electric potential is divided into two: negative charges and positive charges.	1
	3. *Electric potential as a charge at rest:* electric potential is an electric charge which does not possess motion.	1
	4. *Equipotential lines as real lines*: equipotential lines move in a parallel direction.	1
Electric field	5. *Electric field as a substance:* • electric field *flows* from positive to negative • electric field exists due to *flow* of charges through a given surface	2
	6. *Electric lines as a flow of charges*: electric field lines pass through a surface with charges.	1
	7. *Field lines as a flow of potential*: the negative charge is used for storage of electric potential-students considered electric field lines as electric potential.	1
Electric potential energy	8. *Potential energy as a material object:* potential energy *moves* parallel to each other with equal speed.	1
	9. *Kinetic energy as a substance:* when electric potential and charges are *released*, kinetic energy is also *released*.	1
	Extensiveness of ontological alternative conceptions in EPE concepts	**11**

4.1.1.4 Category 4: Ohm's Phenomenological Primitives

The Ohm's p-prim is one of the phenomenological primitives (diSessa, 1993) that could be reflected by physics students who consider Ohm's law as a fundamental law of electricity and magnetism (see paragraph 9 in Section 2.3.1). In both conceptual areas of EM selected for this study, the Ohm's P-Prime category of alternative conceptions was reflected in the focus groups discussions of the students.

Ohm's P-Primes in the Concepts of EPE

In the concepts of EPE, four alternative conceptions were identified and categorized as Ohm's p-primes namely in electric potential (two) and in electric potential energy (two). For example, students discussed that when distance from a charge increases electric potential also increases (see Table 4.6). In this case, the students considered electric potential as it increases proportional to the position. All the Ohm's P-Primes were discussed only once in the focus groups.

Table 4. 6: Pre intervention Ohm's P-Primes in the concepts of EPE with their frequency and extensiveness

Concepts		Ohm's P-Primes in EPE concepts	Frequency
Electric potential	1.	When distance from a charge increases electric potential also increases.	1
	2.	An electric potential is directly proportional to kinetic energy.	1
Electric field & energy	3.	In an electric field, electric potential energy and kinetic energy of a charge are directly proportional.	1
	4.	Electric potential energy is directly proportional to the distance.	1
		Extensiveness of Ohm's P-Primes in EPE concepts	4

Ohm's P-Primes in the Concepts of EMI

Only three alternative conceptions which focused to the induced emf/current concept were categorized as Ohm's p-primes in the EMI conceptual area (see Table 4.7).

Table 4. 7: Pre intervention Ohm's P-Primes in the concepts of EMI with their frequency and extensiveness

Concepts		Ohm's P-Primes in EMI concepts	Frequency
Induced emf/induced current	1.	Current in one coil is proportional to induced emf in another coil.	2
	2.	In an induction involves two nearby coils, the current in the first coil is inversely proportional the emf in the second coil.	2
	3.	Circuit model: current in one coil is related to voltage in another nearby coil based on their connection type (series or parallel); for series coils, the induced current is constant but in parallel coils, induced voltage is constant.	1
		Extensiveness of Ohm's P-Primes in EMI concepts	5

4.1.1.5 Category 5: Mixed Alternative Conceptions

In this study, a mixed conception was meant for an alternative conception that was viewed to have characteristic features of at least two of the predetermined categories (see paragraph 3 in Section 3.7.1.2). Mixed Conceptions were identified in both EPE and EPI concepts selected for this study.

Mixed Conceptions in the Concepts of EPE

Table 4.8 illustrates the alternative conceptions which were identified and categorized into the mixed conceptions. There were two mixed conceptions analyzed in this category which had characteristics of naïve physics, lateral alternative conception and Ohm's P-Prime.

Table 4. 8: Pre intervention Mixed Conceptions in EPE concepts with their frequency and extensiveness

Concepts	***Mixed type***	***Mixed Category Alternative Conceptions in EPE***	***Frequency***
Electric field	*Naïve physics and Lateral alternative conception*	1. *Motion of changes in a field as capacitor's charging process:* In a uniform electric field, a positive charge moves to the positive terminal and a negative charge moves to the negative terminal.	1
Energy	*Naïve physics and Ohm's p-primes*	2. *Total energy increases and they are proportional to each other*: when a charged particle is released in a uniform electric field, its energy will increase and become positive. i.e., when potential energy increases the kinetic energy also increases. Here, the students conceived as if both are directly proportional to each other.	2
		Extensiveness of mixed conceptions in EPE concepts	**3**

Mixed Conceptions in the Concepts of EMI

In the concepts of EMI, two mixed conceptions were analyzed. One was a mix of naïve physics and lateral alternative conception while the other was a mix of naïve physics and Ohm's P-Prime (see Table 4.9).

Table 4. 9: Pre intervention mixed conceptions in EPE concepts with their frequency and extensiveness

Concepts	Mixed type	Mixed Category Alternative Conceptions in EMI	Frequency
Induced current and/or induced emf	Naïve physics and lateral alternative conception	1. Naïve circuit model: An emf is induced only in a closed coil of wire (naïve physics). Students considered an emf as induced current (lateral alternative conception).	1
	Naïve physics and Ohm's P-Primes	2. Coils as a source for induced current/induced emf: Induced current and voltage are produced from coils of wire (*naïve Physics*), because when number of turns of a coil is increased the induced current is also increased (*Ohm's p-prime*).	1
		Extensiveness of mixed alternative conceptions in the concepts of EMI	**2**

4.1.1.6 Category 6: Loose Ideas

Loose ideas are meant for incorrect students' descriptions that were believed not to be attached to any of the four predetermined categories (see paragraph 3 in Section 3.7.1.2). The conceptions in this theme have characteristics of flexibility that pose a problem not to definitely categorize them into either the predetermined or the mixed category.

Loose Ideas in the Concepts of EPE

Table 4.10 presents the loose ideas discussed by the students in the EPE concepts. For example, electric potential is a potential that depends on given two charges was one of the students' conceptions categorized into the loose ideas theme. In this case, it was impossible to be certain whether the students conceived the electric potential as a force, as electric energy or as a summation of the potentials of the two charges because all these concepts are dependent on a system of two charges. This conception was discussed by three of the focus groups.

Table 4. 10: Pre intervention loose ideas in the concepts of EPE with their frequency and extensiveness

Concept	Loose ideas	Frequency
Electric potential	1. *Electric potential depends on two given charges*. In this case, no evidence was shown by the students whether they described the potential of two charges or they considered electric potential as electric potential energy.	3
	2. Electric potential is related to kinetic energy.	1
Energy	3. Equipotential energy is the energy stored in a charge at equal distances. The students did not mention whether they described equipotential lines or electric potential energy.	1
	Extensiveness of loose ideas in EPE concepts	**5**

Loose Ideas in the Concepts EMI

Table 4.11 illustrates only one loose idea identified in the EMI concepts. In this idea, the students did not definitely mention the type of relation that could result electromagnetic induction.

Table 4. 11: Pre intervention loose idea in the concept of EMI with its frequency and extensiveness

Loose idea	Frequency
Electromagnetic induction is any relationship between electricity and magnetism.	1
Extensiveness of loose idea in the concepts of EMI	1

4.1.2 Categories of Conceptual Knowledge

Tables 4.12 & 4.13 show the students' conceptual knowledge in both EPE and EMI concepts. Two types of conceptual knowledge, hierarchical and relational, were categorized. Hierarchical conceptual knowledge refers to classification and categorization of concepts into correct ontological and/or lateral categories (Chi, 2008). In addition, an organization of concepts from a more to less inclusive concept(s) can be named as hierarchical conceptual knowledge (see paragraph 4 in section 2.3.2). Relational conceptual knowledge refers to the construction of relationships between pieces of information (Long, 2005) (see paragraph 5 in section 2.3.2).

4.1.2.1 Category 7: Hierarchal Conceptual Knowledge

In the data of students' focus groups discussions, hierarchical conceptual knowledge was observed only in the concepts of EPE. Consequently, three statements that were believed to have characteristics of hierarchical conceptual knowledge were analyzed (see Table 4.12).

Table 4. 12: Pre intervention students' conceptual knowledge in the concepts of EPE

Category	Pre intervention students' conceptual knowledge	Frequency		
		CPS class	CCS class	All FGD
Hierarchical	1. Electric potential is a scalar quantity.	1		1
	2. Electric potential energy is a type of energy due to charges.	1		1
	3. Electric field is a vector.		1	1
Relational	1. If there is a charge there will be electric potential and electric field.	2	2	4
	2. Electric potential is directly related to charge.	2	1	3
	3. If the electric force between two charges is calculated, then it is possible to calculate the electric potential energy.	2		2

	4. Electric potential energy is a product of electric potential and charge.	1		1
	5. Electric field and electric potential are directly proportional to each other.	2		2
	6. The potential difference at equipotential is zero		1	1
	7. On equipotential the work done is zero because work is directly proportional to the potential difference		2	2
	8. Electric potential energy is directly proportional to charges		2	2
	9. The electric field influences the electric potential value.		1	1
	Total number and extensiveness	7 (11)	7 (10)	12 (21)

4.1.2.2 Category 8: Relational Conceptual Knowledge

In the data of students' focus groups discussions, relational conceptual knowledge theme was observed in both EPE and EMI conceptual areas. Relational conceptual knowledge was less extensively discussed in the EMI concepts than EPE in the concepts (see Tables 4.12 & 4.13).

Table 4. 13: Pre intervention students' conceptual knowledge in the concepts of EMI

Category	Pre intervention students' conceptual knowledge	Frequency		
		CPS class	**CCS class**	**All FGD**
Relational	1. As electric flux is created by a charge, magnetic flux is occurred due to a magnet.	1		1
	2. Induced current is produced by electromotive force.	1		1
	3. Magnetic field is the region of a space in which electric current or moving charges experience force.	1		1
	4. Magnetic flux is created due to magnetic field.		1	1
	5. Movement of a magnet or a coil can produce induced current.		1	1
	6. Magnetic flux equals the product of a magnetic field, an area and cosine of an angle between the magnetic field and the normal line perpendicular to the area.		1	1
Total	**Total number and extensiveness**	**3 (3)**	**3 (3)**	**6(6)**

4.1.3 Distribution of Students' Conceptions in the Categories

Table 4.14 presents a summary of categories of students' conceptions in the two conceptual areas selected for this study. The students' conceptions in the diagnosed categories were presented in terms of their distribution, frequency and extensiveness in order to guide the interpretation of the results.

Table 4. 14: Distribution of students' conceptions in the concepts of EPE and EMI with their frequency and extensiveness of the categories

	Category	*Conceptual area*	*Distribution of Students' Conceptions*	*Frequency*				*Extensiveness*
				4	3	2	1	
Alternative conceptions	Naïve physics	EPE	17 (27.9%)	-	-	6	11	23(25.8%)
		EMI	7 (20.6%)	-	-	2	5	9 (23.1%)
		EPE & EMI	24 (25%)	-	-	8	16	32 (25%)
	Lateral	EPE	14 (22.9%)	-	2	4	8	22 (24.7%)
		EMI	15 (44.1%)	-	-	1	14	16 (41.0%)
		EPE & EMI	29 (31%)	-	2	5	22	38 (30%)
	Ontological	EPE	9 (14.8%)	-	-	2	7	11 (12.4%)
		EMI	-	-	-	-	-	-
		EPE & EMI	9 (9%)			2	7	11 (9%)
	Ohm's p-primes	EPE	4 (6.6%)	-	-	-	4	4 (4.5%)
		EMI	3 (8.8%)	-	-	2	1	5 (12.8%)
		EPE & EMI	7 (7%)	-	-	2	5	9 (7%)
	Mixed	EPE	2 (3.3%)	-	-	1	1	3(3.4%)
		EMI	2(5.9%)	-	-	-	2	2 (5.1%)
		EPE & EMI	4 (4.2%)	-	-	1	3	5 (4%)
	Loose Ideas	EPE	3 (4.9%)	-	1	-	2	5(5.6%)
		EMI	1 (2.9%)	-	-	-	1	1 (2.6%)
		EPE & EMI	4 (4.2%)	-	1	-	3	6 (5%)
	Total	EPE	***49(80.3%)***	-	**3(6.1%)**	**13(26.5%)**	**33(67.3%)**	**68(76.4%)**
		EMI	***28(82.4%)***	-	**-**	**5(17.9%)**	**23(82.1%)**	**33 (84.6%)**
		EPE & EMI	***77(81.1%)***		**3(3.9%)**	**18(23.4%)**	**56(72.7%)**	**101 (78.9%)**
Conceptual knowledge	Relational	EPE	9(14.8%)	1	1	4	3	18(20.2%)
		EMI	6 (17.6%)	-	-	-	6	6 (15.4%)
		EPE & EMI	15 (16%)	1	1	4	9	24 (19%)
	Hierarchical	EPE	3 (4.9%)	-	-	-	3	3(3.4%)
		EMI	-	-	-	-	-	-
		EPE & EMI	3 (3%)	-	-	-	3	3 (2%)
	Total	EPE	***12(19.7%)***	**1(8.3%)**	**1(8.3%)**	**4(33.3%)**	**6(50%)**	**21 (23.6%)**
		EMI	***6 (17.6%)***	**-**	**-**	**-**	**6(100%)**	**6 (15.4%)**
		EPE & EMI	***18(18.9%)***	**1(5.6%)**	**-**	**4(22.2%)**	**12(66.7%)**	**27(21.1%)**
Total		EPE	**61**	**1(1.6%)**	**4(6.6%)**	**17(27.9%)**	**39(63.9%)**	**89**
		EMI	**34**	**-**	**-**	**5 (14.7%)**	**29(85.3%)**	**39**
		EPE & EMI	**95**	**1(1%)**	**4(4.2%)**	**22(23.2%)**	**68(71.6%)**	**128**

The table illustrated that the percentage distribution of the number of students conceptions (81.1%) in the categories and the corresponding extensiveness (78.9%) were comparable. This means that high percentages of the students' conceptions were discussed only once (72.7%) and twice (23.4%) in the four focus groups. Only 3.9% of the students alternative conceptions were discussed three times in the focus groups and no alternative conception was discussed by all the four focus groups. These results showed that the students' conceptions in the categories were diversified and vacillated among the students.

In both EPE and EMI conceptual areas, the percentage distribution of alternative conceptions was greater than 80%, while the distribution of the conceptual knowledge was less than 20%. This means that there is exceedingly greater distribution of the students' alternative conception than their conceptual knowledge which showed that the students' conceptual understanding in the concepts in EPE and EMI were incredibly low.

In addition, the distributions of alternative conceptions and conceptual knowledge in both EPE and EMI were compared (see Table 4.14). As a result, on the one hand, the distribution of the number of alternative conceptions was slightly less in EPE concepts (80.3%) than in the EMI concepts (82.4%). On the other hand, the distribution of the number of conceptual knowledge was slightly greater in EPE concepts (19.7%) than in the EMI concepts (17.6%). Correspondingly, the extensiveness of alternative conceptions and conceptual knowledge in both EPE and EMI were also compared (see Table 4.14). The extensiveness of the alternative conceptions was less in EPE concepts (76.4%) than in the EMI concepts (84.6%) while the extensiveness of the conceptual knowledge was greater in EPE concepts (23.6%) than in the EMI concepts (15.4%). Therefore, based on these results, it could be concluded that the concepts in EMI were more difficult to understand for the focus group students than the concepts in EPE.

Furthermore, from the total number of conceptions identified in all the categories (95 conceptions), 61(64%) of them were in the EPE concepts while 34 (32%) were in the EMI concepts. This showed that the students' experiences are more related to the concepts of EPE than to the concepts of EMI.

4.1.4 Inconsistency of the Alternative Conceptions

Table 4.15 presents the inconsistency of the students' alternative conceptions in the concepts of EPE and EMI within and across the categories. For example, the alternative conceptions of electric potential emerged in all the existing categories. These alternative conceptions were electric potential as a force (lateral alternative conception), rest implies electric potential (naive physics), electric potential as a material object (ontological alternative conception), electric potential is proportional to distance (Ohm's P-Prime) and electric potential could be related to kinetic energy (loose idea). Besides, within the category of lateral alternative conceptions, the electric potential was considered as a force, energy, a vector and a current.

Similarly, inconsistencies were observed in the students' alternative conceptions of the EMI concepts. For example, within the lateral alternative conceptions, induced emf was considered as a potential difference, magnetic field and force. Therefore, in both EPE and EMI concepts, the students' alternative conceptions were inconsistently revealed within and across the categories.

Table 4. 15: Inconsistency in the students' alternative conceptions of EPE and EMI concepts

Category	Concepts in EPE	Concepts in EMI
	Electric potential	**Induced emf**
Naïve physics	• Rest implies electric potential • Potential of two opposite charges system is zero • The potential difference is the difference between positive and negative potentials • The potential difference of charges separated by large distance is zero • An electric potential is confined only in an atom • Equipotential lines have only circular structure • A changed body has only one type of charges	• Magnetic field implies induced current • Magnet implies induced current • Presence of coils implies emf • Constant current implies constant emf
	Electric field	
	• Positive change is the only source of electric field • Uniform electric field implies a uniform velocity • In a uniform electric field, positive charge accelerates; while negative charge decelerates • Uniform electric field implies a projectile	
	Energy	
	• Kinetic energy of a charge is constant in a uniform electric field • Kinetic and potential energies are constant in an electric field • Positive charges have positive energy; negative charges have negative energy. • Work is done on an equipotential line • Moving charges have no potential energy • Kinetic energy of a charge changes on an equipotential line	
	Electric potential	
Lateral alternative conceptions	• Electric potential as a force • Electric potential as an attractive force • Electric potential as potential energy • Electric potential as kinetic energy • Electric potential as a vector • Electric potential as charge flow/current • Electric potential as position and potential difference as a distance Equipotential lines as electric lines	• Magnetic flux as electric flux • Magnetic flux as a magnetic field • Electromagnetic induction as charges flow in magnetic field • Electromagnetic induction as a process of charging • Electromagnetic induction as conduction current • Charging by induction process as electromagnetic process • Induced emf as a potential
	Electric field	
	• Electric field as a force • Electric field as a magnetic field	

	Energy • Electric energy as a force • Electric potential energy as potential difference • Electric potential energy as kinetic energy • Electric potential energy as a vector	difference • Induced current as magnetic field • Induced emf as magnetic field • Induced emf as a force
Ontological alternative conceptions	**Electric potential** • Electric potential as material object • Electric potential as charges • Electric potential as a charge at rest • Equipotential lines as real lines	
	Electric field • Electric field as a substance • Electric lines as a flow of charges • Field lines as a flow of potential	
	Energy • Potential energy as a material object • Kinetic energy as substance	
Ohm's p-Primes	**Electric potential** • An electric potential is proportional to distance • Electric potential proportional to kinetic energy	• Current in one coil is proportional to induced emf in another coil. • In an induction involves two nearby coils, the current in the first coil is inversely proportional the emf in the second coil
	Energy • In an electric field, electric potential energy and kinetic energy of a charge are directly proportional to each other • Electric potential energy is directly proportional to the distance	
Mixed conceptions	**Electric Field** • Motion of changes in a field as capacitor's charging process	• An emf is induced only in a closed coil of wire • A coil with a number of turns is used as a source for induced current/induced emf
	Energy • The total energy of a charge increases and they are proportional to each other	
Loose ideas	**Electric Potential** • Electric potential depends on a given two charges. Electric potential could be related to kinetic energy.	
	Energy • Equipotential energy is the energy stored in the charge at equal distances	

4.2 Qualitative Results of Concept Maps Data

Similar to the FGD data results, the qualitative data results of the students' concept maps (CM) were mainly to answer the first research question which is about the categories of students' conceptions in the conceptual area of EPE and EMI. That is, the results of the research question 'What are the categories of students' conceptions in the electric potential and energy (EPE) and electromagnetic induction (EMI) conceptual areas before intervention?' were analyzed.

However, the results in this subsection were based on individual students' responses while the results of the previous subsection were based on group of students' responses.

The thematic framework analysis was used when analyzing the data collected with CM (see Section 3.8.1). This analysis was applied step by step from the first stage of familiarization to the last stage of the interpretation. Then, the transcribed and coded data were categorized into categories of students' conceptions.

4.2.1 Categories of Students' Alternative Conceptions

Six categories of students' alternative conceptions progressed. These were the naive physics, lateral alternative conceptions, ontological alternative conceptions, phenomenological primes, mixed conceptions and loose ideas. Among these, the first four categories were the presupposed categories from the literature review. These were naive physics, lateral alternative conceptions and ontological alternative conceptions and phenomenological primes. In addition, similar to the FGD results, mixed conceptions and loose ideas identified.

However, in the CM data results, unlike in the FGD results, the phenomenological prime was developed as a category of alternative conceptions while the Ohm's p-prime was developed as a subcategory (subset) of phenomenological primes. This was the main distinction observed between the group-based data and individual-based data on the results of the first research question.

4.2.1.1 Category 1: Naïve Physics

The naive physics was one of the categories developed from the students' alternative conceptions in both EPE and EMI conceptual areas. There were in total eight naïve physics in the concepts of EPE and seven in the concepts of EMI diagnosed with an extensiveness of 9 and 51, respectively (see Tables 4.16 & 4.17).

Naïve Physics in the Concepts of EPE

The number of naïve physics developed in the concepts of EPE was comparable with its extensiveness that almost each naïve physics conception appeared once (see Table 4.16). This shows that there were no frequently revealed naïve physics in the EPE conceptual area. However, only one of the naïve physics which was the students' perception of potential difference as the difference between potentials of two charges was revealed twice (see Table 4.16). In this case, the students simply perceived the potential difference as the difference between the potentials of positive and negative electric charges. Accordingly, the students failed to understand that the potential difference of a charge is due to the difference in positions from the charge.

Table 4. 16: Naïve physics category in the concepts of EPE

Concepts	Naïve physics category in EPE concepts	Frequency
Electric potential	1. Electric potential exists only on equipotential lines.	1
	2. Electric potential is potential at location of a charge.	1
Potential difference	3. Potential difference is the difference between potentials of two charges.	2
	4. Charge implies potential difference.	1
	5. Potential difference implies kinetic energy.	1
Electric field	6. Electric field causes charge.	1
Energy	7. Equipoterntial lines are lines on which kinetic and potential energies remain constant or equal.	1
	8. Energies (potential and kinetic) exist only in the charges.	1
	Extensiveness	**9**

In addition, the revealed naïve physics of the concepts of electric potential, potential difference and energy are found inconsistently in this category. As illustrated in Table 4.16, the first two naive physics described the electric potential. The first one described the electric potential as it exists only on equipotential lines while the second described the electric potential as it exists only at the location of charge. These different naïve physics about the concept of electric potential were inconsistent with each other. Similarly, the naïve physics of potential difference concept was described as: a charge implies potential difference and potential difference is the difference between potentials of two charges. These categories of naïve physics were also inconsistent with each other. The reason was based on the students' description of potential difference. In the former naïve physics, a student considered only one point charge; while in the latter naive physics a student considered two point charges. In addition, regarding the electric energy concept, inconsistent naive physics were revealed that described constant kinetic and electric potential energies independently in equipotential lines and also described the existence of both kinetic and electric potential energies only in the charges. In general, the students' naïve physics in the concepts of EPE are inconsistent and less frequently revealed.

Naïve Physics in the Concepts of EMI

Table 4.17 presents the revealed naïve physics in the EMI conceptual area with respect to their frequency and extensiveness.

Table 4. 17: Naïve physics category in the concepts of EMI

Concepts	Naïve physics in EMI concepts	Frequency
Induced emf and/or induced current	1. Magnetic field lines imply induced emf	19
	2. Magnetic field implies induced emf	16
	3. Magnetic flux implies induced emf/ induced current	6
	4. Current implies induced emf	6
	5. Potential difference implies induced emf	2
	6. Conservative electric field as an effect of induction: Faraday's law states electric field	1
	7. An induced emf shows the presence of induced current.	1
	Extensiveness	**51**

In the concepts of EMI, naïve physics were highly concentrated in relation to the concept of an induced emf and/or an induced current. The first two naïve physics were frequently revealed in comparison to the other alternative conceptions in the category. In this two naïve physics, the students' independently considered magnetic field lines and magnetic field as the causes for induced emf. This means that these two naïve physics were the most considerably revealed alternative conceptions from the entire categories. The second two naïve physics appeared with similar frequencies. This means, the magnetic flux and the current were independently considered as the causes for an induced emf with equal frequencies (see Table 4.17). In the last three naïve physics, the frequency was so low that the conceptions were slightly revealed in the category (see Table 4.17). In addition, the last conception in the table uniquely revealed naïve physics. A student with this naïve physics failed to understand the presence of an induced emf in an open circuit. Another uniquely appeared naïve physics was the depiction of static electric field as an effect of Faraday's Law of induction. In this case, the student failed to understand the difference between the conservative and the non-conservative electric fields. It is the non-conservative time dependent induced electric field which is caused by electromagnetic induction. However, the student considered the conservative electric field as the effect of an electromagnetic induction.

In general, based on the identified and categorized naïve physics in the concepts of EMI, most of the students failed to understand the cause for induced emf which is the time rate of change of magnetic flux. For example, the students considered magnetic flux as a cause for an induced emf. In this case, the students might have some intuitive reasons for their explanations. But, they were unable to visualize that an induced emf is caused by the time rate of change of magnetic flux and it cannot be produced by a constant magnetic flux. In addition, although there was no single consistent naïve physics identified in this conceptual area, the frequency and extensiveness of naïve physics were comparatively higher in the EMI concepts than in the EPE concepts.

4.2.1.2 Category 2: Lateral Alternative Conceptions

There were several alternative conceptions identified and then categorized into the lateral alternative conceptions in both the EPE and EMI concepts. The alternative conceptions in this category were presented in the next two subsections.

Lateral Alternative Conceptions in the Concepts of EPE

Table 4.18 illustrates lateral alternative conceptions in the EPE concepts. There were totally 14 alternative conceptions in this category. The entire lateral alternative conceptions in the concepts of EPE was the most extensively described category (extensiveness=52) as compared to the other categories. In addition, the lateral alternative conceptions in EPE concepts were diversified; but there was a frequently revealed lateral alternative conception which a considerable number of students (n=13) interchanged and failed to differentiate electric potential and electric potential energy (see Table 4.18). In other words, the students of this conception attached descriptions of electric potential to that of energy and vice versa. As illustrated in Table 4.18, there were also considerable students' lateral alternative conceptions (n=6) that the students interchange vector field lines with scalar field lines, like electric field lines as equipotential lines and equipotential lines as magnetic field lines.

There were also incorrectly described lateral alternative conceptions (n=5), such as consideration of an electric field as a magnetic field and an electric field as an electric potential, electric field as a cause for Faraday's Law of induction and electric field lines as a cause for formation of magnetic flux. Besides, students incorrectly labeled electric potential under some properties of electric field (n=5). This means that they considered electric potential as an electric field. Though electric potential and electric field can share some properties and they are found in the same ontological category; laterally, they belong to different subcategories. Another lateral alternative conception was the students' consideration of an electric flux as a magnetic flux. For example, they imagined electric charge as a source of magnetic flux (see number 8 in Table 4.18).

Table 4. 18: Lateral alternative conceptions in the concepts of EPE

Concepts	Lateral alternative conceptions in EPE concepts	Frequency
Electric potential	1. *Interchange of potential and potential energy*, considering electric potential as an electric potential energy and vice versa. For example, electric potential is divided into potential energy and kinetic energy; Electric potential can be change into kinetic energy.	13
Potential difference	2. *Potential difference is considered as an energy*, examples are: • Potential difference is the difference between potential energy and kinetic energy • Potential difference is due to motion of electric charges	4
Electric field	3. *Electric field as electric potential*: e.g., Electric field is represented by equipotential lines.	5
	4. *Electric field is considered as magnetic field*: • Electric field produces electromagnetic induction (Electric field causes Faraday's law of induction) x4 • Electric field lines can form magnetic flux.	5
	5. Gauss' law of electricity as Faraday's law of induction • Electric charges are explained by Faraday's law (3)	3
	6. *Vector field lines are considered as scalar field lines*, such as: • Electric field lines can be equipotential lines (3) • Equipotential lines are magnetic field lines (3)	6
Electric flux	7. Electric flux as electric field, e.g. kinetic & potential energies of a charge are due to electric flux.	2
	8. Electric flux as Magnetic flux • Electric charge in an equipotential gives magnetic flux • Electric field produces magnetic flux • Electric charge produces magnetic flux • Electric potential energy (possessed by charges) results magnetic flux	4
Energy	9. *Energy is considered as a force,* examples are • Electric potential energy is an electrostatic force. • Kinetic energy moves electric charge.	3
	10. *Electric potential energy as electric field:* • Potential energy results in electric flux. • Potential energy gives electric field lines.	3
	11. *Potential energy is described as a capacitance*: • Electric potential energy can be a capacitance.	1
	12. *Electric potential energy as an electric flux*: for example, a student described as if electric potential energy can be an electric flux.	1
	13. Kinetic energy as electric potential energy • Electric potential energy is found in the form of motion of charges.	1
	14. Kinetic energy is considered as a flow of electric charge.	1
	Extensiveness	**52**

Also, there were students (n=3) who mismatched Gauss's law of electricity with Faraday's law of induction. For example, they considered electric charge as a cause for the Faraday's Law of induction (see number 5 in table 4.18). That is, they visualized a charge as an essential concept for induction instead of a charge as a source for an electric flux.

Further, there were students (n=4) who considered a potential difference as energy. Examples are students' consideration of potential difference as the difference between potential energy and kinetic energy and their perception of motion of electric charges as the cause for potential difference (see number 2 in Table 4.18).

There were students (n=3) who considered electric potential energy as electric force. These students also considered kinetic energy as a cause for motion of an electric charge. In addition, electric potential energy as electric field lateral alternative conception was observed in some students' concept maps (n=3). These students considered electric potential energy as a cause for electric flux because they represented electric potential energy by electric field lines.

Furthermore, as illustrated in Table 4.18, there were lateral alternative conceptions depicted with a frequency of one each. These were the students' description of potential energy as a capacitance and an electric flux. There were also students' descriptions of kinetic energy as electric potential energy and as a flow of electric charges.

The lateral alternative conceptions of EPE concepts were also inconsistently revealed. Examples were that the electric potential and potential difference were independently considered as energy (see numbers 1 & 2 in Table 3.18). Also, electric field was independently considered as electric potential and magnetic field (see numbers 3 &4 in Table 4.18). Furthermore, the electric potential energy was considered as: a force, a kinetic energy, a capacitance, an electric field and an electric flux (see numbers 9, 10, 11 & 12 in Table 4.18). These results showed inconsistency of the students' lateral alternative conceptions in the concepts of electric potential and energy.

In the concepts of EPE, the number and the extensiveness of lateral alternative conceptions (14, 52) were higher than the number and the extensiveness of naïve physics (8, 9) (see Tables 4.16 & 4.18).

Lateral Alternative Conceptions in the Concepts of EMI

In the conceptual area of EMI, 10 students' alternative conceptions (with extensiveness =25) were categorized into lateral alternative conceptions (see Table 4.19).

Table 4. 19: Lateral alternative conceptions in the concepts of EMI

Concepts	Lateral alternative conceptions in EMI concepts	Frequency
Induced emf and Induced current	1. *Induced emf as a potential difference* • Electromagnetic induction is measured by potential difference (2) • Magnetic field lines cause potential difference • Potential difference is proportional to induced current (incorrect crosslink)(2) • Potential difference is due to electric field according to Faraday's law (2)	7
	2. *Induced emf as a force* • Induced emf is a force in electromagnetic induction • Magnetic force can induce current • Electromagnetic induction gives magnetic force • Faraday's law is related to electric force (Faraday's law as Coulomb's law)-(Emf as electrostatic force)	4
	3. *Induced emf & induced current as vectors:* Induced current is a vector; Induced emf is a vector	2
	4. *Induced current as kinetic energy* • Induced current is kinetic energy	1
Magnetic field	5. *Magnetic field as magnetic flux* • Magnetic field is magnetic flux which is stated by Faraday's law	1
Magnetic flux	6. *Magnetic flux as emf:* magnetic flux is described by Faraday's law (2); Induced emf can be magnetic flux; Faraday's law deals with magnetic flux	4
Electromagnetic induction/ Faraday's law	7. *Electromagnetic induction process was considered as charging process* • Induced emf is produced in a capacitor • Faraday's law can be divided into series capacitor and parallel capacitor.	2
	8. *Faraday's law as Lenz's law:* Faraday's law determines directions of induced emf and induced current	1
Field lines	9. *Vector field lines as scalar field lines:* magnetic field lines can be equipotential lines; in a magnetic field there are magnetic field lines which are equipotential lines	2
	10. *Magnetic lines as electric lines:* magnetic field lines are in to and out of a magnet	1
	Extensiveness	**25**

The relatively extensive lateral alternative conception (n=7) was students conception of an induced emf as potential difference between two points in a static electric field (see number 1 in Table 4.19). Though potential difference and induced emf have the same unit (volt), they have different sources. The former is related to conservative electrostatic field while the later is connected to the non-conservative electric field (induced electric field). In other words, the students who imagined *induced emf as potential difference* were unable to differentiate the potential difference (the work done by electrostatic field per unit charge) from the induced emf (the work done by time dependent non-electrostatic field per unit charge).

Subsequently, two lateral alternative conceptions of students were depicted with comparably low extensiveness (n= 4 each) in the concepts of EMI (see numbers 2 & 6 in Table 4.19). These were the students' imagination of *an induced emf as a force* and *magnetic flux as an induced emf.* The students of the former conception perceived an induced emf as a magnetic force exerted to move charged particles in the process of electromagnetic induction while the students of the latter conception were noticed to have lack of understanding of the difference between magnetic flux and time rate of change of magnetic flux. In other words, they were not aware of the concept of an induced emf in terms of the rate of change of magnetic flux.

Also, three lateral alternative conceptions (with frequency of two each) were identified (see numbers 3, 7 & 9 in Table 4.19). These were the students' thoughts of the electromagnetic induction process as a charging process, scalar field lines as vector field lines and induced emf and/or current as vectors. In addition, the students thought as if a capacitor is used to induce emf during its charging process. In other words, students of this conception were confused with the concept of a capacitor and an inductor (a coil).

The misclassification of scalar and vector field lines by the students was mainly seen with their view of magnetic field lines as equipotential lines (see number 9 in Table 4.19). In this case, the students mismatched the concentric circles around a point charge (equipotential lines) to a magnetic field lines. In addition, the clockwise or anticlockwise sense of induced current in a closed loop contributed to their conception of emf and/or induced current as vectors. This confusion of the students was arisen due to their misunderstanding of the Lenz's law.

Lastly, four lateral alternative conceptions that considered induced current as kinetic energy, magnetic field as magnetic flux, magnetic lines as electric lines and Faraday's law as Lenz's law were less extensively revealed (frequency of one each) (see number**s** 4, 5, 8 & 10 in Table 4.19).

4.2.1.3 Category 3: Ontological Alternative Conceptions

In the results of this study, ontological alternative conceptions emerged frequently and extensively in the concepts of EPE than in the concepts of EMI (Tables 4.20 & 4.21). In the concepts of EMI, only one ontological alternative conception, i.e., magnetic field as a substance was identified (see Table 4.21).

Ontological Alternative Conceptions in the Concepts of EPE

In the concepts of EPE, five ontological alternative conceptions (with extensiveness of 13) were revealed. This showed that students' ontological alternative conceptions were appeared less extensively than lateral alternative conceptions (with extensiveness of 52) (see Tables 2.18 & 3.20).

Table 4. 20: Ontological alternative conceptions of the students in the concepts of EPE

Concepts	Ontological alternative conceptions in EPE concepts		Frequency
Electric potential energy	1	Students perceived potential energy as a source for electric field. • An electric potential energy is an electric charge.	4
Electric field	2	Students described field lines as real lines • Electric field can *produce* electric field lines. • Electric charges *form* electric field lines. • Equipotential lines are defined as lines *flow* equally from electrically charged area.	3
	3	Electric field as flow of charges • The flow of electric charges makes electric field. • Electric charges change motion of electric field. • Electric field causes magnetism (electric field as a moving charge)-incorrect crosslink	3
	4	Electric field as charges • Electric field can be positive or negative. • Electric fields are electric charges.	2
Potential difference	5	Potential difference as electric charge • Potential difference can be electric charge.	1
		Extensiveness	**13**

As shown in Table 3.20, there were students (n=4) described electric potential energy as charge and vice versa. Also, the description of electric field lines as real lines was another ontological alternative conception. For example, some students (n=3) described electric field lines as a real entity under the ontological category of substance or matter. Another example was the students' consideration of electric field as flow of electric charges (see number 3 in Table 4.20). The flow of electric charges is a process that the students matched it to the field concept. They imagined electric field as a substance that moves like a material body. The students' description of electric field as charges was also another ontological conception (see number 4 in Table 4.20).

The ontological alternative conceptions in the concepts of EPE also showed inconsistency. As illustrated in Table 4.20, electrical potential energy, electric field and potential difference were independently considered as charges (see numbers 1, 4 & 5 in Table 4.20).

Ontological Alternative Conceptions in the Concepts of EMI

Table 4. 21: Ontological alternative conception in the concepts of EMI

Concepts	Ontological alternative conceptions in EMI concepts	Frequency
Magnetic field	Magnetic field as a substance: magnetic field is magnetic substance.	1

The ontological alternative conception in the concepts of EMI is a unique category in which only one alternative conception emerged. Therefore, the ontological category of alternative conceptions in the concepts of EMI concepts is an inconsiderable result to this study.

4.2.1.4 Category 4: Phenomenological Primitives

As describe in Section 2.3.1, the P-Primes category is meant for alternative conceptions that are smaller pieces of fragmented knowledge structures abstracted from students' relatively primitive experiences lacking explanations. Though the Ohm's P-Primes category was presupposed, the P-Primes as a category was emerged from students' concept maps in the concepts of the EM (see Tables 4.22 & 4.23). As a result, the analysis of the students' CM data directed the researcher to consider the Phenomenological Primitives (P-Primes) (diSessa, 1993) rather than the Ohm's P-Primes as a category. As a category of alternative conceptions, the P-Primes are more inclusive than the Ohm's P-Primes (see paragraphs 8 & 9 in Section 2.3.1). Thus, the Ohm's P-Prime was made to be assigned as a subcategory (see Table 4.22).

P-Primes in the Concepts of EPE

There were four P-Primes with extensiveness of five depicted in the EPE concepts. Out of these, three of them were the Ohm's P-Primes (see Table 4.23). For example, electric charge is proportional to induced current, and electric potential energy and kinetic energy of a charge in an electric field are directly proportional to each other. In this regard, it was noticed that students' P-Primes were fragmented that they were found unable to relate their description to the conservation of energy principle.

Students also considered inter-related concepts as independently fragmented concepts with no relationships. For example, electric charge and electric field were considered as independent concepts in electricity (see number 4 in Table 4.22).

Table 4. 22: Phenomenological Primitives of the students in the concepts of EPE

P-Primes in EPE concepts	Frequency
Ohm's P-Primes	3
1. Electric charge is proportional to induced current (incorrect crosslink).	
2. Electric field lines are proportional to equipotential lines.	
3. Electric potential energy of a charge is proportional to its kinetic energy.	
Fragmented pieces of knowledge	2
4. Electric charge and electric field were considered as independent concepts:	
• In electricity there are electric charge and electric field.	
• In electric field there are electric charges.	
Extensiveness	**5**

As its name implies, the P-Primes are described as independent pieces of knowledge. Thus, the conceptions reveled and categorized into this category were fragmented and disintegrated pieces of ideas. Accordingly, the P-Primes were diversified within it and they were less extensively revealed in comparative to the other categories of alternative conceptions.

P-Primes in the Concepts of EMI

In the concepts of EMI, the students' alternative conceptions were also noticed in the form of fragmented descriptions of concepts (n =18) and Ohm's P-Primes (n =4) (see Table 4.23). For example, several students extensively considered induced emf and induced current as two independent concepts in electromagnetic induction. In this regard, the students failed to understand the dependence of induced current on an induced emf. Also less extensively, the students considered magnetic field and magnetic force as independent concepts in electromagnetic induction. The Ohm's P-Primes, like students' thought of 'magnetic flux is proportional to electric charge' was also depicted from the students' concept maps.

Table 4. 23: Phenomenological Primitives in the EMI concepts

Category	Students' alternative conceptions in EMI concepts	Frequency
P-primes	***Fragmented pieces of knowledge***	
	1. Induced emf and induced current are considered as independent concepts. • Electromagnetic induction (divided into or has two forms) - induced emf and induced current.	16
	2. Magnetic field and magnetic force are considered as independent concepts. • Magnetism is branched into magnetic field, magnetic force, electromagnetic induction & magnetic field lines.	2
	Ohm's p-primes	4
	3. Magnetic flux is proportional to equipotential lines (incorrect crosslink).	
	4. Induced current gives induced emf.	
	5. Induced emf depends on induced current.	
	6. Magnetic flux is proportional to electric charge (incorrect crosslink)	
	Extensiveness	**22**

The P-Primes of EMI concepts were less diversified but extensively revealed. In addition, these P-Primes were inconsistently revealed. For example, as shown in table 4.23, the students depicted contradictory conceptions regarding induced emf, such as: induced emf and induced current are independent concept; induced current gives induced emf and induced emf depends on induced current.

4.2.1.5 Category 5: Mixed Alternative Conceptions

As described in Section 4.1.1.5, mixed alternative conceptions were emerged as a category to represent the students' incorrect descriptions of the concepts that were categorized into more than one predetermined category. Accordingly, six alternative conceptions in the concepts of EPE and EMI were identified and categorized into the mixed conceptions (see Table 4.24). These mixed alternative conceptions were diversified and less extensively described.

Mixed Alternative Conceptions in EPE concepts

There were four mixed alternative conceptions in the concepts of EPE. For example, students' conception of 'electric potential is zero on an equipotential line' was a mixed alternative conception (see number 1 in Table 4.23). The reason was that two categories of alternative conceptions (naïve physics and lateral alternative conception) were mixed in this conception. On the one hand, the conception is naïve physics in the sense that a potential at a point could be zero, for example, at an infinite distance from a point charge. On the other hand, the conception can be lateral alternative conception because it is the potential difference that becomes zero on any equiptential line. In other words, this shows that a student was mismatching between electric potential and potential difference. Another example, a charge at rest/in motion was considered as kinetic energy. This was categorized as mixed conception that involved ontological and lateral alternative conceptions. The reason was that charge is a property of matter while its motion is a process (electric current). In addition, kinetic energy is a process that a moving body posses. Therefore, a student consideration of a charge at rest or in motion as kinetic energy was meant to have both incorrect categorization of the concept charge (ontological and lateral alternative conceptions).

Table 4. 24: Mixed conceptions in EPE and EMI concepts

Concepts		Mixed alternative conceptions	Frequency
EPE	1.	Electric potential is zero on an equipotential line (mixed naïve physics and lateral alternative conception).	1
	2.	Charge motion implies electric field. (mixed naïve physics and lateral alternative conception)	1
	3.	Potential difference is uniform in an equipotential line. (mixed naïve physics and lateral alternative conception)	1
	4.	Charge implies kinetic energy irrespective of its state.(ontological and lateral)	1
		Extensiveness	**4**
EMI	5.	Potential difference is due to magnetic field according to Faraday's law. (naïve physics & lateral alternative conception)	1
	6.	Magnetic flux is proportional to electric charge (incorrect crosslink) - (Ohm's p-prim & lateral alternative conception)	1
		Extensiveness	**2**

Mixed Alternative Conceptions in the concepts of EMI

As shown in Table 4.24, there were two emerged mixed conceptions of students in the concepts of EMI. These were the students' consideration of potential difference as if it is due to magnetic field according to Faraday's law and magnetic field is proportional to electric charge. In the former, a student considered potential difference as an induced emf (lateral alternative conceptions) and magnetic field as a cause for induced emf (naive physics). In the latter, a student considered charge as a source for magnetic flux (lateral alternative conceptions) and magnetic flux is proportional to charge (Ohm's P-Prime).

4.2.1.6 Category 6: Loose Ideas

The loose ideas were descriptions of the students that could not firmly categorized into one or more categories of the students conceptions (se Section 4.1.1.6). For example, students' conception of 'energy implies induced emf/current' (see Table 4.25) was considered as *loose idea,* because the students' did not specify the form of energy resulted the induced emf. Was it the energy needed to change the magnetic flux or the energy due to flow of electric current in a coil? Certainly, some energy, either mechanical or electrical, is needed to change the magnetic flux that results an induced emf; however, none of them were mentioned by the students.

In addition, there were students (n=4) that had attempted to express electric field in terms of the Faraday's law of induction. However, the students did not describe clearly the type of electric field that could be explained by the law. As a result, the conception was considered as a loose idea (see Table 25) because it is the Faraday's law of induction that can explain the non-electrostatic time dependent induced electric field not the electrostatic electric field.

Table 4. 25: Loose Ideas in EPE and EMI concepts

Category	*Loose Ideas in EPE and EMI*	**Frequency**
Loose Ideas	1. Energy implies induced emf/current	5
	2. Electric field is explained by Faraday's law or electromagnetic induction results in an electric field (crosslink)	4
	Extensiveness	**9**

4.2.2 Categories of Conceptual Knowledge

Besides the alternative conceptions categories, two categories of the students' conceptual knowledge developed as *hierarchical* and *relational* conceptual knowledge (see Section 4.1.2).

4.2.2.1 Category 7: Hierarchical Conceptual Knowledge

In this study, one statement each, in EPE and EMI concepts, was identified and categorized into hierarchical knowledge (see Table 4.26).

Hierarchical Conceptual Knowledge in the Concepts of EPE

In the concepts of EPE, only one alternative conception that a student described as: electric potential can be determined by potential difference, was considered as hierarchical conceptual knowledge because the concept of electric potential could be explained in terms of potential difference. This means, the concept of electric potential was considered as a more general concept than the concept of potential difference.

Hierarchical Conceptual Knowledge in the Concepts of EMI

In the EMI concepts, a student's description of 'magnetic field is a vector' was considered as hierarchical conceptual knowledge because the vector concept is more inclusive than the concept of magnetic field.

Table 4. 26: Categories of conceptual knowledge in the concepts of both EPE and EMI

Category	conceptual area	conceptual knowledge	Frequency
Hierarchical	EPE	1. Electric potential can be determined by potential difference.	2
		Extensiveness	2
	EMI	1. Magnetic field is a vector.	1
		Extensiveness	**1**
Relational	EPE	1. Electric potential energy can be changed into kinetic energy.	4
		2. Electric potentials on an equipotential line are equal.	1
		3. Electric field can be related to electric potential	3
		4. Electric potential energy depends on potential difference	3
		5. Electric charge creates electric field.	4
		6. Electric charges cause electric potential energy.	1
		7. Electric field causes electric flux.	1
		8. Electric potential is due to electric charge.	1
		Extensiveness	**18**
	EMI	1. Magnetic field gives magnetic flux.	5
		2. Magnetic flux is directly proportional to magnetic field.	2
		3. Induced emf causes flow of electron (induced current)	1
		Extensiveness	**8**

4.2.2.2 Category 8: Relational Conceptual Knowledge

The relational conceptual knowledge categories of the students' conceptions in the two conceptual areas of EM were depicted and charted (see Table 4.26). Accordingly, nine and three simple qualitative descriptions of EPE and EMI concepts, respectively, were categorized as relational conceptual knowledge.

4.2.3 Distribution of Students' Conceptions in the Categories

Table 4.27 illustrates the distribution of the students' conceptions in terms of the number and extensiveness of the conceptions in the existing categories.

Table 4. 27: Categorical distribution of the students' conceptions in the Concepts of EPE and EMI

Students' conceptions	Category	EPE concepts		EMI concepts		EPE and EMI concepts	
		No. of students' Conceptions	Extensiveness	No. of students' Conceptions	Extensiveness	No. of students' Conceptions	Extensiveness
Alternative conceptions	Naïve Physics	8 (18%)	9(9%)	7 (23%)	51(46%)	15(20%)	60(27%)
	Lateral	14(32%)	52(50%)	10(33%)	25 (23%)	24(32%)	77(35%)
	Ontological	5(11%)	13(13%)	1(3%)	1 (1%)	6(8%)	14(6%)
	P-Primes	4(9%)	5(5%)	6(20%)	22(20%)	10(13%)	27(12%)
	Mixed	4 (9%)	4 (4%)	2(7%)	2(2%)	6(8%)	6(3%)
	Loose ideas	-	-	-	-	2(3%)	9(4%)
	Total	**35 (80%)**	**83(81%)**	**26 (87%)**	**101 (92%)**	**63 (83%)**	**193 (87%)**
	Percentage difference	1%		5%		4%	
		% of extensiveness > % of number of alternative conceptions					
Conceptual Knowledge	Hierarchical	1(2%)	2 (2%)	1(3%)	1(1%)	2(3%)	3(1%)
	Relational	8(18%)	18(17%)	3(10%)	8(7%)	11(14%)	26(12%)
	Total	**9(20%)**	**20(19%)**	**4(13%)**	**9(8%)**	**13(17%)**	**29(13%)**
	Percentage difference	1%		5%		4%	
		% of extensiveness < % of number of alternative conceptions					
	Total	**44**	**103**	**30**	**110**	**76**	**222**

Totally, 76 students' conceptions were described with corresponding extensiveness of 222. Out of these conceptions, 44 were in the concepts of EPE with extensiveness of 103, while 30 were in EMI concepts with extensiveness of 110. Overall, in both EPE and EMI concepts, 83% of the students' conceptions were their number of alternative conceptions while 17% were that of their conceptual knowledge. Correspondingly, the alternative conceptions were described extensively (87%) while the conceptual knowledge was described less extensively (13%). Thus, these results showed that the students' conceptual knowledge was very low and their concept maps dominantly represented their alternative conceptions.

The percentages of the number of students' conceptions and their corresponding extensiveness can infer an important interpretation. The percentages of the numbers of the alternative conceptions in the categories were slightly less than the percentages of the corresponding extensiveness, but the percentages of the numbers of the conceptual knowledge in the categories were slightly greater than the percentages of their corresponding extensiveness (see Table 4.27). These results showed that the tendency or inclination of the students' conceptions was towards their alternative conceptions, though the slight percentage shifts indicated diversification of the students' conceptions. However, these change of percentage distributions of the number and extensiveness of alternative conceptions and conceptual knowledge was higher in EMI (5%) than in EPE (1%) concepts (see Table 4.27). This confirmed that the concepts of EMI are more difficult than the concepts of EPE to the students.

4.2.4 Inconsistency of the Alternative Conceptions

Similar to the alternative conceptions from the focus groups data, the individual students' alternative conceptions were inconsistent within and across the categories because the individual students made multiple statements of the key concepts in EPE and EMI (Table 4.28). For example, the alternative conceptions of electric potential emerged in the existing categories as: electric potential exists only on equipotential lines (naïve physics), interchange of electric potential and potential energy (lateral alternative conception), potential difference as electric charge (ontological alternative conception) and electric potential is zero on an equipotential line (mixed conception). In addition, within the category of lateral alternative conceptions, the electric potential energy was considered as a force, an electric field, a capacitance, an electric flux, a kinetic energy and a flow of electric charge.

In the EMI concepts, individual students' alternative conceptions were similarly inconsistent. For example, across the categories of alternative conceptions students made multiple conceptions, like magnetic field implies induced emf (naïve physics), magnetic flux as emf (lateral alternative conception), magnetic field as a substance (ontological alternative conception) and thought of magnetic field and magnetic force as independent concepts (P-Prime). Also, within the lateral alternative conceptions, induced emf was considered as a potential difference, a force, a kinetic energy and a vector.

Table 4. 28: Inconsistency in the students' alternative conceptions of EPE and EMI concepts

Category	Concepts in EPE	Concepts in EMI
Naïve physics	**Electric potential**	**Induced emf**
	Electric potential exists only on equipotential lines. Electric potential is potential at location of a charge. Potential difference is the difference between potentials of two charges. Charge implies potential difference. Potential difference implies kinetic energy.	Magnetic field lines imply induced emf. Magnetic field implies induced emf. Magnetic flux implies induced emf/ induced current. Current implies induced emf. Potential difference implies induced emf. Conservative electric field as an effect of induction: Faraday's law states electric field. An induced emf shows the presence of induced current.
	Electric field	
	Electric field causes charge.	
	Energy	
	Equipoterntial lines are lines on which kinetic and potential energies remain constant or equal. Energies (potential and kinetic) exist only in the charges.	
Lateral alternative conceptions	**Electric potential**	**Induced emf**
	Interchange of potential and potential energy. Potential difference is considered as energy.	Induced emf as a potential difference. Induced emf as a force. Induced emf & induced current as vectors. Induced current as kinetic energy.
	Electric field	**Magnetic field and Magnetic flux**
	Electric field as electric potential Electric field is considered as magnetic field Gauss' law of electricity as Faraday's law of induction Vector field lines are considered as scalar field lines Electric flux as electric field Electric flux as Magnetic flux	Magnetic field as magnetic flux Magnetic flux as emf
	Energy	**Faraday's Law and Induction**
	Electric potential energy is considered as a force Electric potential energy as electric field Electric potential energy is described as a capacitance Electric potential energy as an electric flux Kinetic energy as electric potential energy Kinetic energy is considered as a flow of electric charge	Electromagnetic induction process was considered as charging process. Faraday's law as Lenz's law Magnetic lines as electric lines
Ontological alternative conceptions	**Electric potential**	**Magnetic field**
	Potential difference as electric charge	Magnetic field as a substance
	Electric field	
	Students described field lines as real lines. Electric field as flow of charges Electric field as charges	
	Energy	
	Students perceived potential energy as a source for electric field.	
P-Primes	**Electric charge and Induced emf**	
	Electric charge is proportional to induced current (incorrect crosslink)	
		Induced emf
		Induced emf and induced current are considered as independent concepts. Induced current gives induced emf. Induced emf depends on induced current.
	Electric field	**Magnetic field**
	Electric field lines are proportional to equipotential lines.	Magnetic field and magnetic force are

	Electric charge and electric field were considered as independent concepts.	considered as independent concepts. Magnetic flux is proportional to equipotential lines (incorrect crosslink). Magnetic flux is proportional to electric charge (incorrect crosslink).
	Energy	
	Electric potential energy of a charge is proportional to its kinetic energy.	
Mixed conceptions	**Electric potential**	
	Electric potential is zero on an equipotential line (mixed naïve physics and lateral alternative conception). Charge motion implies electric field. (mixed naïve physics and lateral alternative conception).	Potential difference is due to magnetic field according to Faraday's law (naïve physics & lateral alternative conception). Magnetic flux is proportional to electric charge (incorrect crosslink) - (Ohm's p-prim and lateral alternative conception).
	Electric field	
	Charge motion implies electric field (mixed naïve physics and lateral alternative conception).	
	Energy	
	Charge implies kinetic energy irrespective of its state (ontological and lateral).	
Loose ideas	**Electric field and Faraday's Law**	
	Electric field is explained by Faraday's law or electromagnetic induction results in an electric field (crosslink).	
	Energy and induced emf	
	Energy implies induced emf/current.	

PART II: QUANTITATIVE RESULTS

Quantitative data collected with the modified DEEM (see Section 3.7.2.1) and concept maps (see Section 3.7.2.3) will be presented in the next section. In addition, the students' responses were categorized into model states using the quantitative data of the DEEM test (see Section 3.7.2.1). This categorization of the students responses on the DEEM test helped to study the students' level of conceptual knowledge. Moreover, the students' response concentration factor and concentration deviation were compared using paired samples t-test (see section 3.7.2.1) in order to determine whether the students' responses were consistent or not in the DEEM test. Finally, these quantitative results were triangulated with the qualitative FGD and CM results (see Section 4. 5.3)

4.3 Quantitative Results of the Modified Diagnostic Exam of Electricity and Magnetism Data

4.3.1 Concentration Analysis

The concentration analysis method was discussed (see Section 3.7.2.1). In Table 4.29 the concentration analysis results of the students' responses on the adapted DEEM pre test were presented in terms of concentration scores (S) [0, 1] and concentration factors (C_f) [0, 1]. Concentration deviation (C_d) [0, 1] (concentration of students' incorrect responses) was presented to indicate the concentration of students' alternative conceptions. The formulas used to calculate the concentration score, concentration factor and concentration deviation were given in Section 3.7.2.1.

Table 4. 29: Students' response score, concentration factor and concentration deviation with corresponding model states

No	A=n_1	B=n_2	C=n_3	D=n_4	E=n_5	n_c	S	C_f	C_d	Model (S &C_f)	Model (S &C_d)
1	6	10	**14**	6	9	14	0.31	0.04	0.03	**LL**	**LL**
2	17	7	7	11	**3**	3	0.07	0.11	0.07	**LL**	**LL**
3	11	11	**15**	2	5	15	0.33	0.09	0.1	**LL**	**LL**
4	10	**18**	8	6	3	18	0.40	0.12	0.07	**ML**	**ML**
5	12	6	8	**10**	9	10	0.22	0.02	0.03	**LL**	**LL**
6	**16**	8	15	3	3	16	0.36	0.14	0.21	**LL**	**LM**
7	**14**	16	9	5	1	14	0.31	0.14	0.23	**LL**	**LM**
8	8	9	**7**	17	4	7	0.16	0.09	0.12	**LL**	**LL**
9	6	**12**	17	7	3	12	0.27	0.11	0.19	**LL**	**LL**
10	**13**	8	13	6	5	13	0.29	0.06	0.07	**LL**	**LL**
11	**6**	17	11	10	1	6	0.13	0.13	0.16	**LL**	**LL**
12	2	8	11	17	**7**	7	0.16	0.11	0.15	**LL**	**LL**
13	3	9	11	8	**14**	14	0.31	0.06	0.07	**LL**	**LL**
14	1	5	13	**16**	10	16	0.36	0.13	0.18	**LL**	**LL**
15	4	9	**12**	11	9	12	0.27	0.04	0.05	**LL**	**LL**
16	3	6	**15**	15	6	15	0.33	0.12	0.17	**LL**	**LL**
17	6	**22**	9	5	3	22	0.49	0.20	0.07	**MM**	**ML**
18	8	13	8	**12**	4	12	0.27	0.05	0.07	**LL**	**LL**
19	4	11	**12**	13	5	12	0.27	0.07	0.10	**LL**	**LL**
20	7	13	**8**	9	8	8	0.18	0.02	0.03	**LL**	**LL**

21	7	10	9	**13**	6	13	0.29	0.03	0.02	**LL**	**LL**
22	3	11	11	**16**	4	16	0.36	0.11	0.13	**LL**	**LL**
23	**9**	16	13	3	4	9	0.20	0.12	0.18	**LL**	**LL**
24	**18**	6	14	5	2	18	0.40	0.16	0.20	**ML**	**MM**
25	14	11	**11**	6	3	11	0.24	0.07	0.12	**LL**	**LL**
26	**10**	11	13	9	2	10	0.22	0.07	0.11	**LL**	**LL**
27	17	10	13	**3**	2	3	0.07	0.15	0.13	**LL**	**LL**
28	5	9	20	**2**	9	2	0.04	0.17	0.13	**LL**	**LL**
29	**14**	10	8	8	5	14	0.31	0.04	0.03	**LL**	**LL**
30	12	10	14	**7**	2	7	0.16	0.08	0.11	**LL**	**LL**

4.3.2 Categorization of Students' Responses: Students' Model States

The results of the students' responses categorization are presented that were done by combining their response concentration scores with their response concentration factors and concentration deviations (see Table 4.30). Three-levels coding of students' response states were used for each conceptual multiple-choice question of the modified DEEM (see Table 3.9). Furthermore, the possible students' model states categorization (Bao & Redish, 2001) (see Table 3.2) was used to combine concentration scores with concentration factors and concentration deviations.

Table 4. 30: Conceptual questions that were found in the model states

Model state (S and C_f)	**Conceptual question**	**%**	**Model state (S and C_d)**	**Conceptual question**	**%**
HH	No	0%	**HH**	No	0%
LH	No	0%	**LH**	No	0%
LM	No	0%	**LM**	6, 7	6.7%
MM	17	3.3%	**MM**	24	3.3%
ML	4, 24	6.7%	**ML**	4,17	6.7%
LL	1,2,3,5,6,7,8,9,10,11,12,13,14, 15,16,1819,20,21,22,23,25,26, 27,28,29,30	90%	**LL**	1,2,3,5,8,9,10,11,12,13, 14,15,16,1819,20,21,22, 23,25,26,27,28,29,30	83.3%

This result showed that 90% of the students' responses patterns in the diagnostic test during their pre instruction are found in the null model state (LL) or near the random response state (see Table 4.30). Only 10% of their responses occurred in the medium score with low and medium concentration factors (ML and MM). This means that the pattern of students' responses was mostly found in the low concentration score and the low concentration factor.

Similarly, 83.3% of the students' responses pattern was found in the null model state (LL) with low score and low concentration deviation. Only 16.7 % of their response patterns occurred in the medium state (LM, MM and ML) (see Table 4.30). In addition, there were no cases of occurrence of pure states. The pure states are the correct one model state (HH) and the alternative one model state (LH).

Only students' response in one item (item number 17) was found in the medium level (See Table 4.30). This item was about electric potential of two equal and oppositely charged point charges. With regards to this item, about half of the students had chosen the correct answer (see Table 4.29). Similarly, in the results of the focus groups discussions, out of the four focus groups for this study, two of them had described that 'electric potential of two opposite charges system is zero' (see Table 4.1).

4.3.3 Comparing Concentration Factor and Concentration Deviation of Students' Responses

The two concentrations (see Table 4.29) and their corresponding means (see Table 4.31) were independently calculated and considered as two conditions for the sample. Then, the two concentrations (concentration factor and concentration deviation) of students' responses on the 30 items conceptual questions were compared by conducting paired samples t-test.

Table 4. 31: Descriptive Statistics: score, concentration factor and concentration deviation on DEEM

	N	Minimum	Maximum	Mean	Std. Deviation
S	30	0.04	0.49	0.26	0.11
Cf	30	0.02	0.20	0.10	0.05
Cd	30	0.02	0.23	0.11	0.06
Valid N (list wise)	30				

As a result, there was no statistically significant difference between the two concentrations of students' responses, that is, $t(29) = 1.99$, $p > 0.05$ (see Table 4.32). This result was in agreement with the students' responses model state categorization result in Section 4.3.2 that there were no cases of occurrence of pure states in the students' responses.

Table 4. 32: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	C_f - C_d	-0.02	0.04	0.00	-0.03	0.00	-1.99	29	0.06

In other words, the students' responses to both correct and incorrect answers of the multiple choice questions were random. This implied that their scores were dominantly in the extreme low state.

4.4 Quantitative Results of Concept Maps Data

The descriptive statistics of the students' scores with respect to the components of CM were analyzed (see Table 4.33). The propositions, hierarchies, cross-links and examples that appeared on every participant's CM were scored quantitatively based on the scoring rubric (see Appendix F) in which each CM component was measured from 0 (minimum) to 4 (maximum). Hence, the total maximum score of a student would be 16. The average students' score was converted to percentage for the purpose comparison with the other results.

Table 4. 33: Descriptive statistics of students' concept maps scores

CM components	**N**	**Minimum**	**Maximum**	**Mean**
Propositions (out of 4)	34	0.00	2.00	0.57
Hierarchies (out of 4)	34	0.00	2.50	1.00
Cross links (out of 4)	34	0.00	1.00	0.10
Examples (out of 4)	34	0.00	1.50	0.09
Total (out of 16)	34	0.00	5.50	**1.76 (11%)**
Valid N (list wise)	34			

As shown in Table 4.32, the students' average scores on the propositions and the hierarchies were, respectively, 0.57 and 1.0; while their average scores on the cross links and examples were 0.10 and 0.09, respectively. This shows that in the results of the students' concept maps, the propositions and the hierarchies comparatively represented their conceptual knowledge. In other words, the conceptual knowledge of the students involved in this study was relatively represented and reflected with their hierarchical (super-ordinates to subordinates) and simple propositional relationships between few concepts in EPE and EMI. In addition, the results showed that the conceptual knowledge of the students represented by the cross links and examples were so weak that implied that the students lacked in-depth conceptual understanding of the EPE and EMI concepts (see Table 4.33).

Overall, the average score of students' concept maps was 1.76 out of 16 points or 11% (see Table 4.33). This implied that the students' conceptual knowledge in the concepts of EPE and EMI was low. This low students' CM score was in agreement with their low level concentration score on the modified DEEM (see Table 4.30).

4.5 Triangulation of the Pre Intervention Results

To strengthen the validity and reliability of the results, four types of results were presented and triangulated based on the data collected with the FGD, CM and modified DEEM. These were the qualitative results of data collected with the FGD, the qualitative and quantitative results of data collected with the CM and the quantitative results of data collected with the DEEM test. The triangulation enabled the researcher to explain one form of the results (qualitative or quantitative) in terms of the other. To this end, the four pre intervention results were triangulated in three ways. These were triangulation of: the qualitative results of FGD and CM data, the quantitative results of the modified DEEM test and CM data, and the qualitative and the quantitative results.

4.5.1 Triangulation of Qualitative Results

The aim of this chapter was to provide data to answer the first research question about the categories of students' conceptions with regards to the EPE and EMI concepts. Accordingly, the results of the two qualitative data were triangulated at categorical level. The need for this categorical level triangulation of the qualitative results (the results of individual-based CM data and group-based FGD data) was to ensure validity and reliability of the existed categories of the students' conceptions in the context of this study.

In general, according to the results from both the FGD and CM data, six categories of students' alternative conceptions and two categories of conceptual knowledge existed in the concepts of EPE and EMI. These six categories of the students' alternative conceptions were naïve physics, lateral alternative conceptions, ontological alternative conceptions, p-primes (Ohm's p-primes), mixed conceptions and loose ideas. The two categories of conceptual knowledge were hierarchical and relational conceptual knowledge. Almost all of these diagnosed categories of the students' conceptions in the results of both methods of qualitative data collection were similar, except the emergence of the P-Primes as an inclusive category in the results of CM data and the Ohm's P-Primes as a category in the results of FGD data. In the CM data results, the Ohm's P-Prime was considered as a subcategory (see Tables 4.34 & 4.35).

Tables 4.34 and 4.35 illustrate triangulation of the qualitative results from the FGD and CM data in terms of number of students' conceptions in the categories and extensiveness of the categories.

Table 4. 34: Triangulation of categories of students' conceptions in terms of their distribution

Category	**FGD results (Group-based data)**		**CM results (Individual-based data)**	
	Distribution of students' conceptions		**Distribution of students' conceptions**	
	EPE	**EMI**	**EPE**	**EMI**
Alternative conceptions	**49(80.3%)**	**28 (82.4%)**	**35 (80%)**	**26 (87%)**
Naïve physics	17 (27.9%)	7 (20.6%)	8 (18%)	7 (23%)
Lateral	14 (22.9%)	15 (44.1%)	14(32%)	10(33%)
Ontological	9 (14.8%)	-	5(11%)	1(3%)
P-Primes	-	-	4(9%)	6(20%)
Ohm's P-Primes	4 (6.6%)	3 (8.8%)	-	-
Mixed conceptions	2 (3.3%)	2(5.9%)	4 (9%)	2(7%)
Loose ideas	3 (4.9%)	1 (2.9%)	-	-
Conceptual knowledge	**12(19.7%)**	**6 (17.6%)**	**9(20%)**	**4(13%)**
Relational	9(14.8%)	6 (17.6%)	8(18%)	3(10%)
Hierarchical	3 (4.9%)	-	1(2%)	1(3%)

In the results of both qualitative data, the naïve physics and the lateral alternative conceptions were dominantly developed because they were extensively described (more than 50%) by the students. However, on the one hand, in the results of FGD data, the naïve physics category exceeded the other categories in terms of the number of conceptions depicted and their extensiveness. On the other hand, in the results of CM data, the lateral alternative conceptions category exceeded the other categories in terms of its extensiveness and the number of alternative conceptions in the categories.

In both qualitative results, the students' alternative conceptions were considerably more extensive than their conceptual knowledge. This means, the extensiveness of the categories of alternative conceptions was greater than 80%, while extensiveness of categories of conceptual knowledge was less than 20% (see Table 4.35). The less extensiveness of conceptual knowledge in both the focus groups discussions and concept maps showed that the students' conceptual knowledge was low and they lacked in depth conceptual understanding of concepts in EPE and EMI.

Table 4. 35: Triangulation of categories of students' conceptions in terms of their extensiveness

Category	FGD results (Group-based data)		CM results (Individual-based data)	
	Extensiveness		Extensiveness	
	EPE	EMI	EPE	EMI
Alternative Conceptions	**68(76.4%)**	**33(84.6%)**	**83(81%)**	**101 (92%)**
Naïve physics	23(25.8%)	9 (23.1%)	9(9%)	51(46%)
Lateral	22 (24.7%)	16 (41.0%)	52(50%)	25 (23%)
Ontological	11 (12.4%)	-	13(13%)	1 (1%)
P-Primes	-	-	5(5%)	22(20%)
Ohm's P-Primes	4 (4.5%)	5 (12.8%)	-	-
Mixed conceptions	3(3.4%)	2 (5.1%)	4 (4%)	2(2%)
Loose ideas	5(5.6%)	1 (2.6%)	-	-
Conceptual Knowledge	**21 (23.6%)**	**6 (15.4%)**	**20(19%)**	**9(8%)**
Relational	18(20.2%)	6 (15.4%)	18(17%)	8(7%)
Hierarchical	3(3.4%)	-	2 (2%)	1(1%)

Table 4.35 illustrated that the alternative conceptions in the concepts of EMI were more extensive than those in the concepts of EPE while the reverse was true for conceptual knowledge. In short, students' conceptual knowledge of the concepts in EMI was less extensively discussed and described than that of the EPE concepts. This result showed that the electromagnetic induction concepts were more difficult to understand for the students than the electric potential and energy concepts. This result agreed with Planinic (2006) quantitative study of assessment of difficulties in some concepts of electricity and magnetism.

4.5.2 Triangulation of Quantitative Results

The quantitative results were also triangulated using the average scores of the students in the modified DEEM test and their CM. In the DEEM test data, the average concentration score of the students was approximately 0.26 (see Table 4.31). According to Bao and Redish (2001), this score was found in the low score state (0.0 to 0.4) (see Table 3.2). In the concepts maps, the students' average score was only 11%, which was very low (see Table 4. 33). In addition, the students' answers in their CM were more of simple proportional relations (simple relational conceptual knowledge). Moreover, the students' answers in their CM lacked cross-links and examples that were believed to measure their in-depth conceptual understanding. Therefore, the pre intervention quantitative results of the modified DEEM and CM data indicated that the students' conceptual knowledge in the concepts of electricity and magnetism, especially, in the concepts of EPE and EMI was low.

4.5.3 Triangulation of Qualitative and Quantitative Results

Inconsistent students' conceptions of the concepts in EPE and EMI were found within and across the existing categories of alternative conceptions according to the qualitative evaluation in Section 4.1.3, 4.1.4 & 4.2.4 (see Tables 4.14, 4.15 & 4.28). The comparison of the concentration factor and concentration deviation of the students' responses on the DEEM test items was conducted using paired samples t-test. As a result, there was no statistically significant difference between the two concentrations of students' responses, that is, $t (29) = 1.99$, $p > 0.05$ (see Table 4.32). In general, the inconsistencies of the students' conceptions in all the analyses were triangulated. This means that the inconsistency of student conceptions in both qualitative analyses (see Tables 4.15 & 4.28) and the dominant non-modal random response states (LL) in quantitative analysis are in agreement (see Table 4.30). In addition, the insignificant statistical difference between the two concentrations (C_f and C_d) of the DEEM scores was another indication for inconsistency of the students' conceptions (see Table 4.32). Moreover, both the concentration factor and the concentration deviation of the students responses to the DEEM test were found in the low null model state (see Table 4.30), which indicated the inconsistency of the students responses. Therefore, these pre intervention quantitative and qualitative results confirmed that the students' conceptions were inconsistent in the concepts of EPE and EMI.

The extensiveness of the students' conceptual knowledge in both EPE and EMI concepts was generally less than 20% in this pre intervention data analysis (see Table 4.35). Specifically, the extensiveness of students' conceptual knowledge was less in EMI concepts than in EPE concepts (see Table 4.35). This result was triangulated with the low average scores of the students in the DEEM test and their CM (see Tables 4.30 & 4.31). Also, the result was used to explain the low scores of the students' in the quantitative results, because the less extensive the students' conceptual knowledge in the qualitative results implied their low scores in the quantitative results.

Moreover, the categorization of quantitative students' response states indicated that the students' responses were found in the low random response state (LL). This implied that there were no consistent pure model state in the students responses to the DEEM test. Correspondingly, the categorization of qualitative students' conceptions showed that their conceptions were inconsistently diversified in and across the categories developed. Therefore, the low random response state of students' responses to the quantitative diagnostics test was in agreement with the inconsistently appeared and diversified students' conceptions in the qualitative FGD and CM data results.

4.6 Discussion

This pre intervention study was conducted mainly to categorize undergraduate first year physics students' conceptions in the concepts of electric potential and energy and electromagnetic induction in one University in Ethiopia. Besides, the extensiveness of the alternative conceptions in the categories and the inconsistencies of the alternative conceptions within and across the categories were investigated. The first reason was the existence of a research gap with regards to the categories of students' alternative conceptions in the concepts of electricity and magnetism. The second reason was its practical implication for designing both instruction and curriculum. The third reason was its theoretical implication to contribute to the existing disputable perspectives of the structure of students' alternative conceptions (Clark et al., 2011; diSessa et al., 2004; Elby, 2010). Finally, it was to undertake an in-depth mixed methods study by focusing on a few concepts of EM as recommended in earlier studies (Planinic, 2006).

To categorize the existing students' conceptions of the concepts in EPE and EMI in the situation, mainly, the students' FGD and CM data were separately analyzed and then triangulated. During both of these analyses, six categories of alternative conceptions and two categories of conceptual knowledge were diagnosed. The categories of alternative conceptions were naïve physics, lateral alternative conceptions, ontological alternative conceptions, Ohm's P-Primes (Phenomenological

Primitives), mixed conceptions and loose ideas. In addition, relational and hierarchical categories of conceptual knowledge were identified.

The categories have different distributions of students' conceptions. However, the overall percentage distribution of alternative conceptions categories was greater than 80%, while percentage distribution of conceptual knowledge was less than 20% (see Tables 4.14 & 4.27). This means that the students' conceptions identified in the conceptual area of EPE and EMI were dominantly categorized into the categories of alternative conceptions. Among these, the total distribution of naïve physics and lateral alternative conceptions in the students' FGD and CM, respectively, were more than 60% and 50%, (see Table 4.34). These two categories were more dominant than the ontological alternative conceptions and the Ohm's P-Primes and/or P-Primes. In addition, as illustrated in Tables 4.14 & 4.27, the overall extensiveness of categories of alternative conceptions (mostly greater than 80%) was significantly higher than the extensiveness of categories of conceptual knowledge.

In this study, the FGD helped to generate more conceptions than the CM, because the researcher guided the students until no new conceptions were added regarding the concepts under investigation. However, the CM helped to generate specific individual conceptions better than the FGD.

In addition, the inclination of the students' conceptions towards the naïve physics in the FGD was believed to be due to the contribution of the students' discussion towards development of conceptions (group dynamics). Accordingly, it could be argued that the naïve physics is more 'scientific' than the lateral alternative conception. This is due to the fact that naïve physics have some valid elements of a concept or a principle of the physical world (see Section 2.3.1). For example, two students' alternative conceptions revealed in this study can be compared. These are students' understanding of 'electric potential of two opposite charges system is zero' and students' consideration of 'electric potential as a force'. The former is more scientific than the later, because there is a special case at which electric potential of two point charges separated by some distance becomes zero. Thus, the more 'scientific' conceptions of the students' alternative conceptions (the naïve physics) were tended to dominate during their focus groups discussions because it was believed that the group dynamics contributed towards their conceptions.

The distributions of alterative conceptions and their extensiveness showed similar patterns in the existing categories. This means both of them were found to have approximately comparable values. In other words, a category with the largest number of alternative conceptions was found to have the largest of extensiveness of alternative conceptions and vice versa. This also showed the diversification of alternative conceptions in all the categories (see Tables 4.15 & 4.28).

The students' alternative conceptions were not only found in multiple categories but also in multiple conceptions of a concept within a category. For example, the concept of electric potential were considered as a force, as potential energy, as a kinetic energy as a current and as a vector (see Table 4.15). In addition, the electric potential energy was considered as a force, an electric field, a capacitance, an electric flux, a kinetic energy and a flow of electric charge (see Table 4.28). All these conceptions were categorized as lateral alternative conceptions. A similar situation was investigated in the ontological alternative conceptions. As illustrated in Table 4.15, several students considered independently electric potential as a material body and as a charge. In this case, although the dependence of electric potential on charges is known, the students are unaware of the cause and effect relation; instead, they simply consider potential and charge as the same concept that share similar properties. Furthermore, in the Ohm's P-Primes, it was independently considered that electric potential is proportional to distance and also proportional to the kinetic energy (see Table 4.15).

In this study, the students have also multiple conceptions of a concept in different categories (see Table 4.15 & 4.28). As an example, the students' alternative conceptions in the concept of electric potential were found in almost all the existing categories. These were electric potential as charges (ontological alternative conception), as electric potential energy (lateral alternative conception), a zero electric potential for two opposite charges system (naïve physics) and electric potential proportional to kinetic energy (Ohm's P-Prime). This indicates the inconsistency of the students' alternative conception across the categories.

In the four focus group discussions, a total of 95 conceptions (77 alternative conceptions and 18 conceptual knowledge statements) were revealed in the concepts of both EPE and EMI. From all these conceptions nearly no alternative conception (1%) was discussed by all four focus groups; about 4% of the alternative conceptions were discussed three times in the focus groups; 23% of the alternative conceptions were discussed twice in the focus groups and 72% of the alternative conceptions were discussed only once in the focus groups (see Table 4.14). This implied that most of the students' alternative conceptions were inconsistent. In other words, the students' conceptions were vacillated highly among and within the focus groups. This result agrees with the inclusive idea of vacillation of students' conceptions in science concepts (Li et al., 2006; Tao & Gunstone, 1999).

In addition, a total of 76 conceptions (63 alternative conceptions and 13 descriptions of conceptual knowledge) were revealed in the students' CM formation of the concepts (see Table 4.27). The percentages of the total number of the alternative conceptions and their corresponding extensiveness were both comparable and greater than 80% (see Tables 4.34 & 4.35). This comparable number of alternative conceptions and their extensiveness could indicate the inconsistently diversified students' conceptions.

In the aforementioned two paragraphs, although the inconsistencies of the students' alternative conceptions in the categories were described, few alternative conceptions were revealed frequently. From the FGD data, only two lateral alternative conceptions were frequently revealed (n=3) in which the students' considered both electric potential and electric energy as a force (see Table 4.3). In addition, from the CM data results only four alternative conceptions were frequently revealed. These were two naïve physics: magnetic field lines imply induced emf (n= 19) and magnetic field implies induced emf (n=16) (see Table 4.17); one lateral alternative conception: students' consideration of potential as potential energy and vice versa (n=13) (see Table 4.18) and one P-Prime: students' consideration of induced emf and induced current as fragmented independent concepts (n=16) (see Table 4. 23).

Among the alternative conceptions identified in this study, there are some similar alternative conceptions identified in earlier studies. For example, studies (Galili, 1995; Planinic, 2006) have identified 'uniform field implies uniform velocity' naïve conception. Also, Baser and Geban (2007) identified 'a charged body contains only one type of charge' naïve conception. However, most of the ontological and lateral alternative conceptions are newly identified. In addition, alternative conceptions from the naïve physics category, like potential of two opposite point charges is zero; rest implies electric potential; a potential difference of charges separated by large distance is zero; and moving charges have no electric potential energy are newly identified alternative conceptions.

4.7 Summary of the Chapter

This chapter presented and discussed pre intervention results of the study. These were the categorization of students' conceptions before intervention, extensiveness of categories of the students' alternative conceptions and inconsistency of the students' alternative conceptions. In addition, baseline results were presented in this part to be used to measure effectiveness of the intervention in the next chapter.

G*roup-based data* from the FGD and *individual-based data* from the CM were independently analyzed using the framework thematic analysis. In both pre intervention results, six categories of alternative conceptions and two categories of students' conceptual knowledge were identified. Among the categories of alternative conceptions, four were the presupposed categories based on the literature review namely naive physics, the lateral alternative conceptions, the ontological alternative conceptions and the Ohm's P-Primes while the other two that emerged were termed mixed conceptions and loose ideas. The two categories of students' conceptual knowledge were diagnosed as hierarchical and relational conceptual knowledge. The quantitative baseline results show that that 90% of the students' responses patterns in the diagnostic test during their pre instruction are found in the null model state (LL) or near the random response state. In addition, there was no statistically significant difference between the two concentrations of students' responses, that is, $t(29) = 1.996$, $p > 0.05$. This result was in agreement with the students' responses model state categorization result that there were no cases of occurrence of pure states in the students' responses.

CHAPTER 5

POST INTERVENTION RESULTS

In the previous chapter, the qualitative and quantitative results of the pre intervention study were presented and discussed. These results were mainly to answer the first research question. In addition, baseline data that are needed to answer the third research question were obtained.

In this chapter, the qualitative and quantitative results of the post intervention study are presented and discussed. These post intervention results are to answer the second and third research questions. These questions are:

- What are the categories of students' conceptions in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) after intervention?
- How significant is conceptual change through cognitive perturbation using simulations (CPS) as compared to cognitive conflict using simulations (CCS) in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI)?

Data were analyzed and presented both qualitatively and quantitatively in two parts. Part One presented qualitative data and analyses while Part Two presented quantitative data and analyses. Finally, triangulations of the post intervention results were made.

PART I: QUALITATIVE RESULTS

In this part, the results to the second research question which was about categorization of students' conceptions in the concepts of EPE and EMI after intervention were analyzed qualitatively. In other words, the results of the post intervention data from focus groups discussions and concept maps of the students who participated in the study were presented and discussed. Similar to the pre intervention analyses, g*roup-based data* analysis was used to analyze data from the focus groups discussions while *individual-based data* analysis was used when analyzing the concept maps (see paragraph 2 in Chapter 4). Both analyses were separately done using the framework thematic analysis (see Section 3.7.1) step by step starting from the first stage of familiarization to the last stage of interpretation. The transcribed and coded data were then categorized into categories of students' alternative conceptions and conceptual knowledge with respect to the two treatment classes (cognitive conflict with simulations (CCS) and cognitive perturbation with simulations (CPS) classes).

5.1 Qualitative Results of Focus Groups Discussions

From the 45 students who agreed to participate in this study only 34 students took part in the post intervention focus group discussions (see Section 3.3).

5.1.1 Categories of Students' Alternative Conceptions after Intervention

In the post intervention results of the group-based data from the four focus groups (two focus groups in each of the CCS and CPS classes), six categories of alternative conceptions were identified. Among the categories of alternative conceptions, four were the presupposed categories based on the literature review namely naive physics, lateral alternative conceptions, ontological alternative conceptions and Ohm's P-Primes while the other two that emerged were termed mixed conceptions and loose ideas (see Section 4.1.1). The categories of students' alternative conceptions before and after intervention persisted but there were changes in the distribution and extensiveness of the alternative conceptions in the categories.

5.1.1.1 Category 1: Naïve Physics

The naive physics category of the students' alternative conceptions was also identified in the post intervention students' focus group discussions in both CCS and CPS classes.

Naïve Physics of the CCS Class

In the two focus groups of the CCS class, there were a total of 21 alternative conceptions categorized into naïve physics in the concepts of EPE and EMI. Among these, nine of them were in the concepts EPE while 12 were in the concepts of EMI (see Table 5.1).

Table 5. 1: Naïve Physics of CCS and CPS classes in the concepts of EPE and EMI

	Naïve physics of students in CCS class	freq	Naïve physics of students in CPS class	freq
EPE	1. Electric field creates charges.	1	1. Electric field direction is towards positive or negative based on direction of the charges (sign implies direction).	2
	2. Charges have electric potential if they are in electric field.	1	2. A charge in a uniform electric field moves with a constant velocity	2
	3. The potential at the midpoint between two point charges separated by some distance is zero.	2	3. Opposite charges released in an external uniform electric field cannot move	1
	4. A released point charge increases the strength of an electric field.	1	4. Potential difference is the difference between potentials of two opposite charges	1
	5. Positive charge is the only source of electric field.	1	5. Charge motion implies electric potential	1
	6. Uniform electric field implies constant velocity	1	6. Electric potential is only at charge's location	1
	7. Uniform electric field implies uniform electric potential.	1	7. Motion of a charge is in the direction of electric field	1
	8. A charge rotates around a source of uniform electric field.	1	8. A released charge has zero energy	1
	9. Motion implies electric energy.	2		
	Extensiveness of naïve physics in EPE	**11**	**Extensiveness of naïve physics in EPE**	**10**
EMI	1. Rotation of magnetic field creates induced current.	1	1. Magnetic field implies emf	1
	2. Change in time cause emf.	1	2. Magnetic flux implies emf	2
	3. Change in both magnetic field and area of a coil at a time cannot induce emf.	2		
	4. Current in first coil implies emf in the second coil.	1		
	5. Variation of magnetic field implies increase induced current	2		
	6. Change in an area of a coil changes magnetic field	1		
	7. Magnet results electromagnetic induction	1		
	8. Rotation of a coil near a magnet implies electromagnetic induction	1		
	9. Electric charge produces magnetic field.	2		
	10. Presence of a coil and a magnet implies emf.	2		
	11. Magnetic field parallel to an area implies maximum flux; whereas magnetic field perpendicular to an area gives no flux.	1		
	12. The magnetic field makes charge in motion.	1		
	Extensiveness of naïve physics in EMI	**16**	**Extensiveness of naïve physics in EMI**	**3**
	Extensiveness of naïve physics in EPE& EMI	**27**	**Extensiveness of naïve physics in EPE& EMI**	**13**

Naïve Physics of the CPS Class

In the two focus groups of the CPS class there were in total 10 alternative conceptions categorized into naïve physics in the concepts of EPE and EMI. Among these, eight of them were in the concepts EPE while two of them were in the concepts of EMI (see Table 5.1). As illustrated in Table 5.1, the number and extensiveness of naïve physics were less in the CPS class (10, 13) than in the CCS class (21, 27).

5.1.1.2 Category 2: Lateral Alternative Conceptions

Lateral Alternative Conceptions of the CCS Class

In the two focus groups of the CCS class there were seven alternative conceptions categorized into lateral alternative conceptions in the concepts of EPE and EMI. Among these, four of them were in the concepts EPE while three of them were in the concepts of EMI (see Table 5.2).

Table 5. 2: Lateral alternative conceptions of CCS and CPS classes in the concepts of EPE and EMI

	Lateral alternative conceptions of students in the CCS class	**freq**	**Lateral alternative conceptions of students in the CPS class**	**freq**
EPE	1. Electric potential is a vector	1	1. Potential difference is electric potential energy	1
	2. Electric energy and electric potential are vectors because both of them depend on charges.	2	2. A moving charge is a vector but a stationary charge is a scalar (motion implies vector; rest implies scalar).	1
	3. Charge motion implies vector.	2		
	4. Moving charge implies electric potential	2		
	Extensiveness	**7**	**Extensiveness**	**2**
EMI	1. Electromagnetic induction means production of magnetic field.	1	Electromotive force is induced current	1
	2. A magnet and a moving charge cause emf.	1		
	3. Induced current, emf and magnetic flux are vectors	1		
	Extensiveness	**3**	**Extensiveness**	**1**
	Extensiveness of lateral alternative conceptions in EPE& EMI	**10**	**Extensiveness of lateral alternative conceptions in EPE& EMI**	**3**

Lateral Alternative Conceptions of the CPS class

In the two focus groups of the CPS class, there were in total three alternative conceptions categorized into lateral alternative conceptions in the concepts of EPE and EMI. Among these, two were in the concepts EPE while the other one was in the concepts of EMI (see Table 5.2). The number and the extensiveness of lateral alternative conceptions were less in the CPS class (3, 3) than in the CCS class (7, 10) (see Table 5.2).

5.1.1.3 Category 3: Ontological Alternative Conceptions

Ontological Alternative Conceptions of the CCS Class

Only two ontological alternative conceptions were developed in the focus groups discussions of the CCS class (see Table 5.3). These were the students' description of electric potential as a charge, and their consideration of electromagnetic induction process as a *collection* of electric and magnetic fields. This means that the students' pre intervention perception of fields as material bodies persisted after intervention.

Table 5. 3: Ontological alternative conceptions of CCS and CPS classes in the concepts of EPE and EMI

	Ontological Alternative Conceptions of the CCS class	**freq**	**Ontological Alternative conceptions of the CPS class**	**freq**
EPE	Electric potential is a charge.	1	1. Potential difference is a *connection* between positive and negative charges.	1
			2. If electric field *goes* with a charge, then the charge will be accelerated.	1
	Extensiveness	**1**	**Extensiveness**	**2**
EMI	Electromagnetic induction is a *collection* of electric and magnet fields.	1	1. The process of electromagnetic induction as magnetic field	1
	Extensiveness	1	**Extensiveness**	**1**
	Extensiveness of ontological alternative conceptions in EPE and EMI	**2**	**Extensiveness of ontological alternative conceptions in EPE and EMI**	**3**

Ontological Alternative Conceptions of the CPS Class

Three ontological alternative conceptions, two alternative conceptions in the concepts of EPE and one in the concepts of EMI, were developed in the two focus groups discussions of the CPS class (see Table 5.3). The number and extensiveness of these alternative conceptions were slightly greater in the CPS class (3, 3) than in the CCS class (2, 2).

5.1.1.4 Category4: Ohm's P-Primes

Ohm's P-Primes of the CCS Class

Three P-Primes, two of them in the concepts of EPE and one of them in the concepts of EMI, were developed from the focus groups discussions of the CCS class.

Table 5. 4: Ohm's p-primes of CCS and CPS classes in the concepts of EPE and EMI

	Ohm's p-primes of the CCS class	**freq**	**Ohm's p-primes of the CPS class**	**freq**
EPE	1. Electric field varies inversely as the distance.	1		
	2. Electric potential of a charge increases as position of a test charge increases.	1		
	Extensiveness	**2**		
EMI	When motion of a coil increases in a magnetic field, the induced current increased.	1	1. Current in one coil is directly proportional to the voltage in another nearby coil.	2
			2. The relationship between magnetic field and induced current is direct proportional.	1
			3. The stronger the magnetic field the higher its variation.	1
	Extensiveness	1	**Extensiveness**	**4**
	Extensiveness of Ohm's P-Primes in EPE and EMI	**3**	**Extensiveness of Ohm's P-Primes in EPE and EMI**	**4**

Ohm's P-Primes of the CPS Class

As shown in Table 5.4, only three Ohm's P-Primes in the concepts of EMI were identified from the focus groups discussions of the CPS class. The number of Ohm's P-Primes in the CPS and CCS classes was the same, which was three each, but the extensiveness was slightly greater in the CPS class than in the CCS, three in the CCS and four in the CPS.

5.1.1.5 Category 5: Mixed Alternative Conceptions

Mixed Alternative Conceptions of the CCS Class

Two mixed alternative conceptions were identified from the students' focus groups discussions of the CCS class (see Table 5.5). One was a combination of naive physics and lateral alternative conception while the other was a blend of lateral alternative conception and Ohm's P-Prime.

Table 5. 5: Mixed alternative conceptions of CCS and CPS classes in the concepts of EPE

	Mixed conceptions of students in CCS class	freq	Mixed conceptions of students in CPS class	freq
EPE	1. For several charges, the electric potential is directly *proportional* to the sum of the charges *(naïve physics and Ohm's p-prime)*.	1	1. The total potential of several point charges is *directly proportional* to their *total charge (naïve physics and Ohm's p-prime)*	2
	2. Electric potential is proportional to the product of charges (*lateral alternative conceptions and Ohm's p-prime)*	1	2. The total potential of several point charges is *proportional* to the *product of the charges* (*lateral alternative conceptions and Ohm's p-prime)*	2
			3. Electric potential energy is *proportional* to charge (*lateral alternative conceptions and Ohm's p-prim)*	2
			4. The electric potential varies inversely as the *square* of the distance between a point charge and test charge(*lateral alternative conceptions and Ohm's p-prime)*	1
			5. Quantities (electric potential & electric field) which are *proportional* to charges are vectors (*lateral alternative conception and Ohm's p-prime)*	2
	Extensiveness	**2**	**Extensiveness**	**9**

Mixed Alternative Conceptions of the CPS Class

Five mixed alternative conceptions were depicted from the students' focus groups discussions of the CPS class (see Table 5.5). Four of them were a combination of lateral alternative conception and Ohm's P-Prime while one was a blend of naïve physics and Ohm's P-Prime. The mixed alternative conceptions in terms of their number and extensiveness were found greater in CPS (5, 9) class than in CCS class (2, 2) (see Table 5.5).

5.1.1.6 Category 6: Loose Ideas

Only one loose idea was developed in the focus groups discussions of the CCS class (see Table 5.6). There was no such idea depicted in the CPS class.

Table 5. 6: Loose idea of the CCS class in the concepts of EPE

Loose Idea of students in the CCS class	freq
Relation between electric field and magnetic field results electromagnetic induction	1
Extensiveness	1

5.1.2 Categories of Conceptual Knowledge after Intervention

The thematic framework analysis also helped to obtain two categories of students' conceptual knowledge which were named as hierarchical and relational conceptual knowledge (see Section 2.3.2).

5.1.2.1 Category 7: Hierarchical Conceptual Knowledge

Hierarchical Conceptual Knowledge of the CCS class

Six statements of hierarchical conceptual knowledge, three each in the concepts of EPE and EMI, were discussed in the focus groups of the CCS class (see Table 5.7).

Table 5. 7: Hierarchical conceptual knowledge of CCS and CPS classes in the concepts of EPE and EMI

	Hierarchical Conceptual Knowledge of Students in CCS class	**freq**	**Hierarchical Conceptual Knowledge of Students in CPS class**	**freq**
EPE	1. Charge is a scalar	1	1. Charge is a scalar not a vector; it has no direction.	2
	2. Electric potential is a scalar	2	2. Electric potential is a scalar quantity and its addition is a scalar.	2
	3. Electric field is a vector	2	3. Electric field is a vector quantity.	2
			4. Electric potential energy is a scalar	1
	Extensiveness	**5**	**Extensiveness**	**7**
EMI	1. Electromagnetic induction is one way of producing electric current or energy.	1	1. Electromagnetic induction is a process of producing an emf that drives current in a coil.	1
	2. Sources of magnetic field are magnets and moving charges.	2		
	3. Change of magnetic flux is changing of magnetic field by keeping area constant or changing of area by keeping the magnetic field constant	1		
	Extensiveness	**4**	**Extensiveness**	**1**
	Hierarchical Conceptual Knowledge of CCS class	***9***	***Hierarchical Conceptual Knowledge of CCS class***	***8***

Hierarchical Conceptual Knowledge of the CPS class

Five statements of hierarchical conceptual knowledge were discussed in the focus groups of the CCS class (see Table 5.7). Among these, four were in the concepts of EPE while one was in the concepts of EMI. As shown in the table, the students' hierarchical conceptual knowledge in terms of its number and extensiveness was slightly less in the CPS (5, 8) class than in the CCS (6, 9) class.

5.1.2.2 Category 8: Relational Conceptual Knowledge

Relational Conceptual Knowledge of the CCS class

There were in total 13 descriptions that showed relational conceptual knowledge of the students in the CCS class. Among these, seven were in the concepts of EPE while four were in the concepts of EMI (see Table 5.8).

Table 5. 8: Relational conceptual knowledge of CCS and CPS classes in the concepts of EPE and EMI

	Relational Conceptual Knowledge of Students in CCS class	**freq**	**Relational Conceptual Knowledge of Students in CPS class**	**freq**
EPE	1. The existence of electric field shows the presence of charges (Charge implies electric field)	2	1. Electric potential is determined by a charge at a given specific position.	2
	2. Electric potential exists due to a charge (Charge implies electric potential)	2	2. Electric potential is determined by one point charge; but electric potential energy is determined by two charges with separation between them.	2
	3. The relationship between electric field and electric potential is directly proportional	2	3. Electric potential is proportional to charge and inversely to distance	2
	4. Electric potential energy is energy between two or more charges separated by some distances.	2	4. Electric potential and electric field are directly proportional to each other, i.e., $V=Ed$	2
	5. Electric potential is directly proportional to charge.	2	5. Electric potential and energy are directly proportional.	2
	6. Directions of electric field lines are determined by the sign of charges	1	6. The difference between electric potential and electric field is that $E \sim 1/r^2$ but $V \sim 1/r$.	2
	7. Closer means stronger electric field	1	7. Electric potential energy varies directly proportional to the product of two charges and inversely proportional to the distance between them.	2
			8. At a given point, electric potential of several point charges can be added.	2
			9. Charges in an electric field have potential energy.	1
			10. Electric potential difference is equal to work done per unit charge and it is proportional to electric potential energy	2
			11. Electric field is force acting on test charge per positive test charge.	2
	Extensiveness	**12**	**Extensiveness**	**21**
EMI	1. Magnetic flux is created when magnetic field lines are penetrating some area.	1	1. If there is no emf induced a coil then there will be no induced current in the coil.	1

	2. When the number of turns increases, induced current also increases.	1	2. When we increase the number of turns of a coil, the bulb gives more light. So number of turns and emf can be related	1
	3. Relative motion of a magnet and a coil implies induced emf.	2	3. Magnetic flux is the number of magnetic lines that cross a given area perpendicularly	2
	4. Motion of magnetic field source(current carrying coil) in a coil results in induced emf	2	4. Change of a magnetic flux can result an induced emf.	1
			5. Relative motion of a magnet and a coil produces induced emf and induced current in the coil	2
			6. A magnet field can result magnetic flux	2
	Extensiveness	**6**	**Extensiveness**	**9**
	Extensiveness relational conceptual knowledge of CCS class	**18**	**Extensiveness relational conceptual knowledge of CCS class**	**30**

Relational Conceptual Knowledge of the CPS class

There were in total 17 students' descriptions of relational conceptual knowledge in the CPS class. Among these, 11 were in the concepts of EPE while six were in the concepts of EMI. The relational conceptual knowledge was the category in which the two treatment classes showed a significant difference in terms of their number and extensiveness. This means that the number and extensiveness of relational conceptual knowledge were found more in the CPS class (17, 30) than in CCS class (11, 18) (see Table 5.8).

5.1.3 Post Intervention Distribution of Students' Conceptions from their Focus Groups Discussions

A summary of post intervention categories of students' conceptions in the two conceptual areas selected for this study is presented (see Table 5.9). The categories of students' conceptions were analyzed and presented in terms of the number of alternative conceptions, frequency and extensiveness in order to guide the interpretation of the results.

Table 5. 9: Distribution of students' conceptions in the concepts of EPE and EMI with extensiveness of the categories

Category		***Conceptual area***	**CCS Class**				**CPS Class**			
			Number of conceptions	***Frequency*** 2	1	**extensiveness**	***Number of conceptions***	***Frequency*** 2	1	**extensiveness**
Alternative conceptions	Naïve Physics	EPE	9	2	7	11	8	2	6	10
		EMI	12	4	8	16	2	1	1	3
		EPE & EMI	***21***	***6***	***15***	***27***	***10***	***3***	***7***	***13***
	Lateral	EPE	4	3	1	7	2	-	2	2
		EMI	3	-	3	3	1	-	1	1
		EPE & EMI	***7***	***3***	***4***	***10***	***3***	***-***	***3***	***3***
	Ontological	EPE	1	-	1	1	2	-	2	2
		EMI	1	-	1	1	1	-	1	1
		EPE & EMI	***2***	***-***	***2***	***2***	***3***	***-***	***3***	***3***
	Ohm's p-primes	EPE	2	-	2	2	-	-	-	-
		EMI	1	-	1	1	3	1	2	4
		EPE & EMI	***3***	***-***	***3***	***3***	***3***	***1***	***2***	***4***
	Mixed	EPE	2	-	2	2	5	4	1	9
		EMI	-	-	-	-	-	-	-	-
		EPE & EMI	***2***	***-***	***1***	***2***	***5***	***4***	***1***	***9***
	Loose Ideas	EPE	1	-	1	1	-	-	-	-
		EMI	-	-	-	-	-	-	-	-
		EPE & EMI	***1***	***-***	***1***	***1***	***-***	***-***	***-***	***-***
	Total	EPE	19	5	14	24	17	6	11	23
		EMI	17	4	13	21	7	2	5	9
		EPE & EMI	***36 (68%)***	***9 (25%)***	***27 (75%)***	***45 (62%)***	***24 (52%)***	***8 (33%)***	***16 (67%)***	**32 (46%)**
Conceptual knowledge	Hierarchical	EPE	3	2	1	5	4	3	1	7
		EMI	3	1	2	4	1	-	1	1
		EPE & EMI	***6***	***3***	***3***	***9***	***5***	***3***	***2***	***8***
	Relational	EPE	7	5	2	12	11	10	1	21
		EMI	4	2	2	6	6	3	3	9
		EPE & EMI	***11***	***7***	***4***	***18***	***17***	***13***	***4***	**30**
	Total	EPE	10	7	3	17	15	13	2	28
		EMI	7	3	4	10	7	3	4	10
		EPE & EMI	***17 (32%)***	***10 (59%)***	***7 (41%)***	***27 (38%)***	***22 (48%)***	***16 (73%)***	***6 (27%)***	***38 (54%)***
Total		EPE	29	12	17	41	32	19	13	51
		EMI	24	7	17	31	14	5	9	19
		EPE & EMI	**53**	**19**	**34**	**72**	**46**	**24**	**22**	**70**

The percentage of occurrences of alternative conceptions in the pre intervention discussions was greater than 80% while the percentage occurrences of conceptual knowledge was less than 20% (see discussion in section 4.1.3). This showed that before intervention the students' discussions were dominantly more of alternative conceptions than the conceptual knowledge.

However, after intervention, the percentage of occurrences of the students' conceptions in both the CCS and CPS classes showed differences which were compared. In the CCS class, 53 conceptions were identified in all the categories. Among these conceptions, 36 (68%) of them were in the categories of alternative conceptions while 17 (32%) of them were in the categories of conceptual knowledge. In the CPS class, 46 conceptions were identified in all the categories. Among these conceptions, 24 (52%) of them were in the categories of alternative conceptions while 22 (48%) of them were in the categories of conceptual knowledge (see Table 5.9). This showed that the students' conceptual knowledge was discussed more in the CPS class (48%) than in the CCS class (32%). Conversely, the alternative conceptions were discussed more in the CCS class (68%) than in the CPS class (52%) (see Table 4.9).

The percentage distribution of the number of students' alternative conceptions (81%) in the categories and the corresponding extensiveness (79%) were comparable in the pre intervention students' focus groups discussions. Similarly, the percentage distribution of the number of students' conceptual knowledge (19%) in the categories and the corresponding extensiveness (21%) were comparable (see Table 4.14). This indicated that the students' conceptual knowledge in the pre intervention was low.

After the intervention, the percentage distribution of the number of conceptions and the extensiveness in both the treatment classes were analyzed and compared. Accordingly, in the CCS class, the percentage of alternative conceptions and corresponding extensiveness were 68% and 62%, respectively. In the CPS class, the percentage of alternative conceptions and corresponding extensiveness were, respectively, 52% and 46% (see Table 5.9). These showed that, after intervention, the number of alternative conceptions and extensiveness of categories of the alternative conceptions was lesser in the CPS class than in the CCS class.

In addition, in the CCS class, the percentage of the students' conceptual knowledge and the corresponding extensiveness were 32% and 38%, respectively; while in the CPS class, the percentage of the students' conceptual knowledge and the corresponding extensiveness were, respectively, 48% and 54% (see Table 4.9). These showed that the total number of the students' conceptual knowledge and their corresponding extensiveness were more in the CPS class than in the CCS class.

In the pre intervention analysis of the students' FGD, most of the students alternative conceptions (73%) were described only once, 23% of them were described twice and 4% of them were discussed three times in the four focus groups discussions (see Table 4.14). However, this diversification of the students' alternative conceptions was changed after the intervention. In the two focus groups' discussions of the CCS class, 25% of their alternative conceptions were discussed by both of the focus groups while 75% of their alternative conceptions were discussed only once in the two focus groups (see Table 5.9) . In the two focus groups' discussions of the CPS class, 33% of their alternative conceptions were discussed by both of the focus groups while 67% of their alternative conceptions were discussed only once in the two focus groups. This means that after intervention, diversification of the students' alternative conceptions was lesser in the CPS class in than in the CCS class.

In addition, the diversifications of the students' conceptual knowledge after intervention were compared. In the CCS class, 59% of the students' conceptual knowledge was discussed by both of the focus groups while 41% of their conceptual knowledge was discussed once in the two focus groups (see Table 5.9). Similarly, in the CPS class, 73% of the students' conceptual knowledge was discussed by both of the focus groups while 27 % of their conceptual knowledge was discussed once in the focus groups. These indicated that students' conceptual knowledge were more consistent in the CPS class than in the CCS class.

5.2 Qualitative Results of Concept Maps Data

In this study, the results from individual students' concept maps (individual-based data) were used to compare the results obtained from the students focus groups discussions (group-based data). The results in the following section will also be used to supplement and explain the quantitative results from the modified DEEM and CM (see Section 5.4.3).

5.2.1 Categories of Students' Alternative Conceptions after Intervention

In this post intervention analysis of the students' CM, like the pre intervention analysis, five categories of students' alternative conceptions were developed in both the CCS and CCS classes. These were naive physics, lateral alternative conceptions, ontological alternative conceptions, phenomenological primes and mixed conceptions. The loose ideas did not appear in the students' concepts maps of both treatment classes. However, the distribution of the alternative conceptions in the categories and the extensiveness of the categories were different in both the treatment classes.

5.2.1.1 Category 1: Naïve Physics

Naïve Physics of the CCS Class

In the CCS class, there were in total 13 alternative conceptions categorized into naïve physics in the concepts of EPE and EMI. Among these, six were in the concepts EPE while seven were in the concepts of EMI (see Table 5.10).

Table 5. 10: Naïve Physics of CCS and CPS classes in the concepts of EPE and EMI

	Naïve physics of students in CCS class	**freq**	**Naïve physics of students in CPS class**	**freq**
EPE	1. Electric potential produces electric charge.	1	1. Electric potential energy exists in the constant equipotential lines.	1
	2. *Motion implies electric potential*: kinetic energy results electric potential.	1	2. Electric force is due to charges at rest.	1
	3. Electric field causes electric charge	1	3. Electric field results electric charge.	3
	4. Electric potential is zero on equipotential lines.	1	4. An electric potential at a point results kinetic energy	1
	5. Electric potential exist only in equipotential lines	1	5. Electric field is produced from electric charge at rest	1
	6. Potential difference is equal on equipotential line	1		
	Extensiveness	**6**	**Extensiveness**	**7**
EMI	1. Magnetic flux produce induced emf	5	1. Magnetic flux results induced emf	11
	2. Magnetic field produces induced emf	1	2. Magnetic field causes induced current/emf	2
	3. Magnetic field lines produce induced emf.	1	3. Magnetic field lines cause induced current/emf	3
	4. Electric charge produces magnetic field	2	4. Magnetic force acts on an electric charge.	1
	5. Electromagnetic induction is caused by current	1	5. Magnetic flux can cause electric flux	1
	6. Magnetic field lines are like equipotential lines	1	6. Faraday's Law states electric field	1
	7. Magnetic field lines are formed by moving charges	1	7. Magnetic flux can give electric field	1
			8. Magnet cause electromagnetic induction	1
			9. Induced emf is caused by electric potential energy.	1
			10. Electromagnetic induction is caused by electric potential	1
	Extensiveness	**12**	**Extensiveness**	**23**
	Extensiveness of naïve physics in CCS	**18**	**Extensiveness of naïve physics in CPS**	**30**

Naïve Physics of the CPS Class

In the CPS class, there were a total of 15 alternative conceptions categorized into naïve physics in the concepts of EPE and EMI in which five of them were in the concepts of EPE while ten of them were in the concepts of EMI (see Table 5.10). The number and extensiveness of naïve physics depicted with the students' CM were found lesser in the CCS (13, 18) than in the CPS (15, 30).

5.2.1.2 Category 2: Lateral Alternative Conceptions

Lateral Alternative Conceptions of the CCS class

In the CCS class, there were totally 15 alternative conceptions categorized into lateral alternative conceptions in the concepts of EPE and EMI. Among these, ten of them were in the concepts EPE while five of them were in the concepts of EMI (see Table 5.11).

Table 5. 11: Lateral alternative conceptions of CCS and CPS classes in the concepts of EPE and EMI

	Lateral alternative conceptions of students in CCS class	**freq**	**Lateral alternative conceptions of students in CPS class**	**freq**
EPE	1. *Electric potential as electric field*: Electric potential produce electric flux	1	1. Electric potential is electric potential energy	1
	2. *Electric potential as potential difference*: Electric potential produce kinetic energy; Potential difference is an electric potential	2	2. Equipotential lines represents magnetic field; equipotential lines are magnetic field lines	2
	3. *Electric potential as energy*: Electric potential has two types: electric potential energy and kinetic energy.	2	3. *Electric field as magnetic field*: kinetic energy of a charge results in electric field	1
	4. *Potential difference as electric potential energy*: Potential difference is a form of electric potential energy	1	4. Electric potential energy is kinetic energy	5
	5. *Potential difference as kinetic energy:* Potential difference is found in the form of kinetic energy	1	5. *Electric field lines as Equipotential lines:* • Electric field gives equiptential lines;equipotential lines result in electric flux	3
	6. *Electric potential energy as kinetic energy*: Electric potential energy is due to movement of charges	1	6. *Electric flux as magnetic flux*: Electric flux induces emf	1
	7. *Electric potential energy as electric potential:* electric potential energy results equipotential lines; electric potential energy is equal on equipotential lines	2		
	8. *Electric field as magnetic field*: Electric field produces magnetic flux	1		

	9. *Induced electric field as electrostatic electric field*: electric field is describe by Faraday's law	1		
	10. *Electric field as a force*: electric field is given by Coulomb's law	1		
	Extensiveness	**13**	**Extensiveness**	**13**
EMI	1. *Faraday's Law as Gauss' Law*: magnetic field is given by Faraday's law • Magnetic flux is stated by Faraday's law of induction	4	1. *Gauss law as Faraday's law*: Magnetic flux is explained by Faraday's law; Magnetic flux is described by electromagnetic induction; Faraday's law explains electric charge	4
	2. *Magnetic field lines as electric field*: Magnetic field lines produce electric field lines	1	2. Magnetic flux as magnetic field: Magnetic flux is represented by magnetic field lines	2
	3. Magnetic field results induced emf	1	3. Induced current is produced in a capacitor (induced current as displacement current)	1
	4. Magnetic flux is the flow of induced current	1	4. Electromagnetic induction process generates magnetic field	1
	5. Induced emf can be electric potential	1	5. Electric potential is an induced emf	1
	Extensiveness	**8**	**Extensiveness**	**9**
Extensiveness of naïve physics in CCS		**21**	**Extensiveness of naïve physics in CSS**	**22**

Lateral Alternative Conceptions of the CPS class

In the CPS class, there were totally 11 alternative conceptions categorized into lateral alternative conceptions in the concepts of EPE and EMI. Among these, six of them were in the concepts of EPE while five of them were in the concepts of EMI (see Table 5.11). The number of lateral alternative conceptions revealed by the CM was found greater in the CCS class (15) than in the CPS class (11). The extensiveness of lateral alternative conceptions (21, 22) revealed by the CM was found comparable in both the CCS class and CPS class.

5.2.1.3 Category 3: Ontological Alternative Conceptions

Ontological Alternative Conceptions of the CCS Class

This category of alternative conceptions was only developed in the concepts of EPE. In the CCS class, six ontological alternative conceptions were developed (see Table 5.12).

Table 5. 12: Ontological Alternative Conceptions of CCS and CPS classes in the concepts of EPE

	Ontological alternative conceptions of students in CCS class	**freq**	**Ontological alternative conceptions of students in CPS class**	**freq**
EPE	1. Electric potential energy is caused by equipotential lines	1	1. Equipotential lines are combination of potential and field lines.	1
	2. When potential difference *moves*, it gives kinetic energy	1	2. Electric field lines are electric potential energy	1
	3. Electric potential energy as a charge: Electric potential is formed from electric potential energy	1	3. Electric flux is *flow* of electric charges; Electric flux is a current	2
	4. *Electric field as a charge*: electric field can be positive or negative	1		
	5. *Electric charge as electric potential*: Electric charge results in equipotential lines.	1		
	6. *Current as charge:* electric potential difference causes electric charges	1		
	Extensiveness	**6**	**Extensiveness**	**4**

Ontological Alternative Conceptions of the CPS Class

In the CPS class, only three ontological alternative conceptions were developed (see Table 5.12). As illustrated in the table, the number (6, 3) and extensiveness (6, 4) of ontological alternative conceptions were more in the CCS class than in CPS class.

5.2.1.4 Category 4: P-Primes

P-Primes of the CCS Class

In the CCS class, eight P-Primes, four each in both of EPE and EMI concepts, were depicted from the students' concept maps.

Table 5. 13: P-Primes of CCS and CPS classes in the concepts of EPE and EMI

	P-Primes of students in CCS class	**freq**	**P-Primes of students in CPS class**	**freq**
EPE	1. Electric potential produces electric charge and electric field	1	1. Electric field is proportional to charge and distance	1
	2. Electric potential energy is proportional to distance	1	2. In electricity, there are electric field and electric charge	1
	3. Electric field is directly proportional to number of charges and inversely proportional to distance from the charge	1	3. Electric potential energy is proportional to kinetic energy	1
	4. Electric field consists of electric potential and electric charge.	1		
	Extensiveness	**4**	***Extensiveness***	**3**
EMI	1. Magnetic flux is proportional to induced emf	1	1. Induced emf is proportional to magnetic flux.	1
	2. Magnetic flux is magnetic field and magnetic	1	2. Magnetic force is inversely	1

	field lines		proportional to magnetic field	
	3. Magnetic flux consists of magnetic field and magnetic field lines	1		
	4. Magnetic field consists of magnetic field lines and magnetic flux	1		
	Extensiveness	**4**	***Extensiveness***	**2**
Extensiveness of P-Primes in EPE and EMI in CCS		***8***	***Extensiveness of P-Primes in EPE and EMI in CPS***	***5***

P-Primes of the CPS Class

In the CPS class, five P-Primes were depicted from the students' concept maps. Among these, three of them were in the concepts of EPE while two of them were in the concepts of EMI. The number (8, 5) and extensiveness (8, 5) of the students' P-Primes were found more in the CCS class than in the CPS class.

5.2.1.5 Category 5: Mixed Alternative Conceptions

Mixed Alternative Conceptions of the CCS Class

Two mixed alternative conceptions, one each in the concepts of EPE and EMI, were developed from the students' CM formations of the CCS class (see Table 5.14).

Table 5. 14: Mixed conceptions of CCS and CPS classes in the concepts of EPE and EMI

	Mixed Conceptions of students in CCS class	**freq**	**Mixed Conceptions of students in CPS class**	**freq**
EPE	*Lateral and ontological alternative conceptions*: equipotential lines are produced by the *movement* of electric field.	1	*Ohm's p-prime and lateral alternative conceptions*: electric potential is proportional to distance between charges.	1
EMI	*Ohm's p-prime and Naïve physics:* induced emf is directly proportional to strength of the field	1		
	Extensiveness	**2**	***Extensiveness***	**1**

Mixed Alternative Conceptions of the CPS Class

Only one mixed alternative conceptions in the concepts of EPE was identified from the students' CM of the CCS class and no alternative conception was occurred in the concepts of EMI in (see Table 5.14).

5.2.2 Categories of Conceptual Knowledge after Intervention

5.2.2.1 Category 6: Hierarchical Conceptual Knowledge

Hierarchical Conceptual Knowledge of the CCS class

Five statements of hierarchical conceptual knowledge, two in EPE and three in EMI concepts, were depicted from the students' CM of the CCS class.

Table 5. 15: Hierarchical conceptual knowledge of CCS and CPS classes in the concepts of EPE and EMI

	Hierarchical Conceptual Knowledge of Students in CCS class	**freq**	**Hierarchical Conceptual Knowledge of Students in CPS class**	**freq**
EPE	1. Electric field is a vector.	3	1. A charge in electric field can have kinetic energy and potential energy.	7
	2. Electric potential is a scalar	1	2. Electrical potential energy is a scalar	1
			3. Electrical potential energy can be changed to kinetic energy	1
	Extensiveness	**4**	**Extensiveness**	**9**
EMI	1. Electromagnetic induction can be seen in terms of induced current or induced emf	11	1. Electromagnetic induction involves induced emf and induced current	17
	2. Magnetism deals with magnetic effects of magnetic field.	1	2. Faraday's law states electromagnetic induction.	2
	3. Magnetic field is a vector	1		
	Extensiveness	**13**	**Extensiveness**	**19**
Extensiveness of hierarchical conceptual knowledge in EPE& EMI in CCS		**17**	***Extensiveness of hierarchical conceptual knowledge in EPE& EMI in CPS***	**28**

Hierarchical Conceptual Knowledge of the CPS class

Five statements of hierarchical conceptual knowledge, three in EPE and two in EMI concepts, were also depicted from the students' CM of the CPS class. The number of conceptual knowledge of the students in the two treatment classes was equal but their extensiveness were more in the CPS class (28) than in the CCS class (17) (see Table 5.15).

5.2.2.2 Category 7: Relational Conceptual Knowledge

Relational Conceptual Knowledge of the CCS class

There were in total 14 descriptions that showed relational conceptual knowledge of the students in the CCS class. Among these, nine of them were in the concepts of EPE while six of them were in the concepts of EMI (see Table 5.16).

Table 5. 16: Relational conceptual knowledge of CCS and CPS classes in the concepts of EPE and EMI

	Relational Conceptual Knowledge of Students in CCS class	**freq**	**Relational Conceptual Knowledge of Students in CPS class**	**freq**
EPE	1. Potential difference can be related to energy (electric potential energy & kinetic energy).	1	1. Electric field relates to electric potential.	3
	2. Electric field causes electric force on a charge.	1	2. Potential difference is proportional to electric potential energy	2
	3. Kinetic energy can be transformed in to electric potential energy.	2	3. Kinetic energy is proportional to potential difference	2
	4. Electric field gives electric potential energy to a charge.	1	4. Electric potential energy is equal to potential difference times charge, i.e. $\Delta U = \Delta V.q$	4
	5. Electric charge produces electric field	7	5. Electric charge results electric field	2
	6. Electric potential is directly proportional to charge and inversely to the distance	2	6. Electric charge can generate kinetic energy	1
	7. Potential difference can put charge in to motion that gives it kinetic energy	2	7. Electric charge can generate electric potential energy	1
	8. Potential difference can be related to work done on a charge	1	8. Electric potential energy of a charge can be changed to kinetic energy	3
	9. Potential difference is zero on equiptential lines.	2	9. Potential difference is the difference between potentials of two equipotential lines, i.e., $\Delta V = V_b - V_a$	3
			10. Electric potential is expressed in terms of charge and distance, i.e., V=kq/r.	3
			11. Electric charges cause electric force	1
			12. Electric flux is proportional to Electric field.	1
	Extensiveness	**19**	**Extensiveness**	**26**
EMI	1. Induced emf produces induced current	6	1. Magnetic flux is proportional to the product of magnetic field and area	10
	2. Magnetic flux is related to Faraday's law according to $\varepsilon = -\frac{d\Phi}{dt}$	4	2. Induced emf is proportional to induced current	5
	3. Magnetic field causes magnetic flux.	3	3. Magnetic force on a charge is due to its motion.	1
	4. Magnetic flux depends on magnetic field and area	2		

	5. Magnetic field is produced by a moving charge and a magnet.	1		
	Extensiveness	**16**	**Extensiveness**	**16**
Extensiveness of relational conceptual knowledge in EPE and EMI in CCS		**35**	**Extensiveness of relational conceptual knowledge in EPE and EMI in CPS**	**42**

Relational Conceptual Knowledge of the CPS class

There were 15 descriptions that showed relational conceptual knowledge of the students in the CPS class. Among these, 12 of them were in the concepts of EPE while three of them were in the concepts of EMI (see Table 5.16). As shown in the table, the extensiveness of the students' relational conceptual knowledge was found higher in the CPS class (42) than in the CCS class (35).

5.2.2.3 Category 8: Scientific Model

Scientific model is described as a "correct scientific mental model" (Chi et al., 1994; Vosniadou & Brewer, 1994) that may represent changes and generates predictions and outcomes, such as prediction of the direction of electric field of a given source (see Section 2.3.3). Accordingly, scientific model was one of the categories only identified after the intervention.

Scientific Model in the CCS class

There was only one scientific model identified which indicated a student understanding of magnetic field representation. That is, magnetic field lines show the direction of a magnetic field.

Table 5. 17: Students' scientific model in the concepts of EPE and EMI with extensiveness of the categories

	Scientific model of Students in CCS class	**freq**	**Scientific model of Students in CPS class**	**freq**
EPE			1. Electric field is represented by electric field lines	1
			2. Electric potential is represented by equipotential lines.	4
			3. An electric potential is constant on an equipotential line	1
			4. Kinetic energy of a charge is constant in an equipotential line	1
			5. Electric potential lines are field lines	1
			6. Electric potential lines are perpendicular to electric field at a point	1
			Extensiveness	**9**

EMI	Magnetic field lines show the direction of magnetic field	1	Magnetic field is represented by magnetic field lines	9
	Extensiveness	**1**	**Extensiveness**	**9**
Extensiveness of scientific model in EPE& EMI in CCS		**1**	**Extensiveness of scientific model in EPE and EMI in CPS**	**18**

Scientific Model in the CPS class

In the CPS class, seven students' scientific models were depicted in their CM representation of the concepts. Six scientific models were found in the concepts of EPE while only one was obtained in the concepts of EMI. The extensiveness of the scientific models depicted was found significantly more in the CPS class (18) than in the CCS class, which was only one.

5.2.3 Post Intervention Distribution of Students' Conceptions from their Concept Maps

Table 5.18 illustrates the distribution of the students' conceptions in terms of the number of conceptions and extensiveness of the diagnosed categories in both treatment classes.

Table 5. 18: Distribution and extensiveness of the categories of conceptions in the concepts of EPE and EMI

Category		**Conceptual area**	**CCS class**		**CPS class**	
			No conceptions	**extensiveness**	**No conceptions**	**extensiveness**
Alternative conceptions	Naïve physics	EPE	6	6	5	7
		EMI	7	12	10	23
		EPE & EMI	***13***	***18***	***15***	***30***
	Lateral ACs	EPE	10	13	6	13
		EMI	5	8	5	9
		EPE & EMI	***15***	***21***	***11***	***22***
	Ontological ACs	EPE	6	6	3	4
		EMI	-	-	-	-
		EPE & EMI	***6***	***6***	***3***	***4***
	P-primes	EPE	4	4	3	3
		EMI	4	4	2	2
		EPE & EMI	***8***	***8***	***5***	***5***
	Mixed conceptions	EPE	1	1	1	1
		EMI	1	1	-	-
		EPE & EMI	***2***	***2***	***1***	***1***
	Total	EPE	27	30	18	28
		EMI	17	25	17	34
		EPE & EMI	***44(69%)***	***55(51%)***	***35(56%)***	***62(41%)***
Conceptual knowledge	Hierarchical	EPE	2	4	3	9
		EMI	3	13	2	19
		EPE & EMI	***5***	***17***	***5***	***28***
	Relational	EPE	9	19	12	26
		EMI	5	16	3	16
		EPE & EMI	***14***	***35***	***15***	***42***

	Scientific model	EPE	-	-	6	9
		EMI	1	1	1	9
		EPE & EMI	***1***	***1***	***7***	***18***
	Total	EPE	11 (29%)	23 (43%)	21 (54%)	44 (61%)
		EMI	9 (35%)	30 (55%)	6 (26%)	44 (56%)
		EPE & EMI	***20(31%)***	***53(49%)***	***27(44%)***	***88(59%)***
Total		EPE	38	53	39	72
		EMI	26	55	23	78
		EPE & EMI	***64***	***108***	***62***	***150***

Distribution of Conceptions and Extensiveness of the Categories in the CCS class

In the CCS class, 64 students' conceptions were described with the corresponding extensiveness of 108. From these conceptions, 38 were in the concepts of EPE with extensiveness of 53 while 26 were in EMI concepts with extensiveness of 55. Overall, in both EPE and EMI concepts, 69% of the students' conceptions were alternative conceptions, while 31% belonged to conceptual knowledge. Correspondingly, percentage extensiveness of the alternative conceptions and the conceptual knowledge were, respectively, 51%, and 49%. These results showed that the post intervention extensiveness of students' alternative conceptions and their conceptual knowledge were comparable in the CCS class.

Distribution of Conceptions and Extensiveness of the Categories in the CPS class

There were 62 students' conceptions described with corresponding extensiveness of 150 in the CPS Class. From these conceptions, 39 were in the concepts of EPE with extensiveness of 72, while 23 were in EMI concepts with extensiveness of 78. Overall, in both the EPE and EMI concepts, 56% were the number of the students' alternative conceptions while 44% were that of their conceptual knowledge. Correspondingly, percentage extensiveness of the alternative conceptions and the conceptual knowledge were, respectively, 41%, and 59%. Thus, these results showed that the post intervention extensiveness was less for students' alternative conceptions than for their conceptual knowledge. In other words, in the post intervention CM formation of the CPS class, their conceptual knowledge was more extensive than their alternative conceptions.

Comparison of Alternative Conceptions and Conceptual Knowledge of the CCS and CPS Classes

In both the CCS and CPS classes, the percentages of the numbers of the alternative conceptions in the categories were greater than the percentages of their corresponding extensiveness while the percentages of the numbers of the conceptual knowledge in the categories were less than the percentage of their corresponding extensiveness (see Table 4.18). These results showed that after intervention the tendency or inclination of the students' conceptions was towards their conceptual knowledge.

As illustrated in Table 5.18, in the CCS class, the percentages of number of alternative conceptions and corresponding extensiveness were, respectively, 69% and 51%; while in the CPS class, the percentages of number of alternative conceptions and corresponding extensiveness were, respectively, 56% and 41%. These results showed that the students' alternative conceptions after intervention had more number and extensiveness in the CCS class than in the CPS class.

Alternatively, as illustrated in Table 5.18, in the CCS class, the percentages of number of conceptual knowledge and corresponding extensiveness were, respectively, 31% and 49%; while in the CPS class, the percentages of number of alternative conceptions and corresponding extensiveness were, respectively, 44% and 59%. These results showed that the students' conceptual knowledge after intervention had more number and extensiveness in the CPS class than in the CCS class.

PART II: QUANTITATIVE RESULTS

In this part, the results of the cognitive perturbation strategy using simulations (CPS) and cognitive conflict strategy using simulations (CCS), used to support the students learning in the two treatment classes, the CPS class and the CCS class, are presented and compared, respectively. The results obtained in chapter four were used as baseline in this chapter to compare the students' conceptual change after the intervention. In short, this part was to answer the third research question: How significant is conceptual change through cognitive perturbation using simulation (CPS) as compared to cognitive conflict using simulation (CCS) in the conceptual areas of electricity and magnetism?

In this section, quantitative data was collected after the interventions with the modified DEEM (see Section 3.7.2.1) and concept maps (see Section 3.7.2.3) were analyzed, presented and compared with the pre intervention results. In addition, the students' responses in the CCS and CPS classes were categorized into model states using the quantitative data of the DEEM test (see Section 3.7.2.1). This categorization of the students responses on the DEEM test helped to compare the students' level of conceptual knowledge in the CCS and CPS classes after the interventions.

5.3 Post Intervention Results of DEEM Data

5.3.1 Students' Scores Levels

The students' response states to the modified DEEM post test is presented in Table 5.19. The students' scores and concentration factors with their corresponding levels for the two treatment classes were analyzed. The scores and concentration factors were, respectively, analyzed using equations 1 and 2 in Section 3.7.2.1. The classification of the students' response states into three levels was based on the categorization scheme discussed in section 3.7.2 and presented in Table 3.2.

Table 5. 19: Post intervention students' scores and concentration factors of the two treatment classes

Item No	**CCS Class**			**CPS Class**		
	S	**C_f**	**level**	**S**	**C_f**	**level**
1	0.26	0.18	**LL**	0.40	0.19	**ML**
2	0.05	0.55	**LH**	0.10	0.08	**LL**
3	0.63	0.44	**MM**	0.60	0.36	**MM**
4	0.53	0.27	**MM**	0.50	0.37	**MM**
5	0.32	0.16	**LL**	0.50	0.32	**MM**
6	0.37	0.21	**LM**	0.35	0.07	**LL**
7	0.26	0.28	**LM**	0.65	0.47	**MM**
8	0.32	0.13	**LL**	0.20	0.08	**LL**
9	0.58	0.33	**MM**	0.40	0.15	**ML**
10	0.26	0.18	**LL**	0.30	0.09	**LL**
11	0.05	0.22	**LM**	0.40	0.12	**ML**

12	0.00	0.14	**LL**	0.20	0.16	**LL**
13	0.16	0.11	**LL**	0.60	0.38	**MM**
14	0.58	0.36	**MM**	0.40	0.15	**ML**
15	0.42	0.15	**ML**	0.35	0.07	**LL**
16	0.32	0.07	**LL**	0.45	0.21	**MM**
17	0.74	0.56	**HH**	0.80	0.67	**HH**
18	0.58	0.37	**MM**	0.55	0.33	**MM**
19	0.21	0.12	**LL**	0.55	0.28	**MM**
20	0.37	0.13	**LL**	0.35	0.11	**LL**
21	0.63	0.41	**MM**	0.45	0.22	**MM**
22	0.05	0.15	**LL**	0.45	0.17	**ML**
23	0.32	0.15	**LL**	0.40	0.22	**MM**
24	0.37	0.24	**LM**	0.30	0.09	**LL**
25	0.21	0.08	**LL**	0.30	0.14	**LL**
26	0.37	0.10	**LL**	0.40	0.12	**ML**
27	0.11	0.24	**LM**	0.15	0.05	**LL**
28	0.11	0.13	**LL**	0.35	0.14	**LL**
29	0.42	0.18	**ML**	0.40	0.19	**ML**
30	0.05	0.16	**LL**	0.25	0.06	**LL**

Students' scores levels were categorized separately for the two treatment classes (see Table 5.20) in which 70% and 40% of the students' responses in the CCS and CPS classes were, respectively, found in the low score level. Also, 26.7% and 56.7% of the students' responses in the CCS class and CPS class were, respectively, found in the medium score level. These results showed that the CPS strategy was better than the CCS strategy in transforming the students' responses states from low to medium score levels. However, the two strategies did not show difference in shifting the students' response level from medium to high because the high score level of the two classes was the same, 3.3% each. This was because the students' initial (pre intervention) response states were dominantly (90%) found in the low level (see Table 4.29 in section 4.3.2). Accordingly, the students lacked cognitive resources (necessary background in conceptual knowledge) that made them unable to reach to the high response level.

Table 5. 20: Students' Scores levels of the CCS and CPS classes

Levels	CCS Class Responses	CPS Class Responses
Low	21 (70%)	12(40%)
Medium	8 (26.7%)	17 (56.7%)
High	1(3.3%)	1(3.3%)

5.3.2 Model Categorization of the Students' Responses

The post intervention responses of the students in the CPS and CCS classes to the modified DEEM post test were analyzed, categorized and presented. These were done by combining the students' response concentration scores with their response concentration factors (see Table 5.19). Three-levels coding of students' response states were used for each conceptual multiple-choice question of the modified DEEM (see Table 3.9). Furthermore, the possible students' model states categorization (see Table 3.10) was used to combine concentration scores with concentration factors.

Table 5. 21: Categories of the CCS and CPS students' responses

Model States		Explanation	CCS Class	CPS Class
One model state (Pure state)	HH	One correct model	1(3.3%)	1(3.3%)
	LH	One dominant incorrect model	1 (3.3%)	-
Two models state	LM	Two possible incorrect models	5 (16.7%)	-
	MM	Two popular models	6 (20%)	10(33.3%)
	ML	Two non popular models	2 (6.7%)	7 (23.3%)
Null model state	LL	Near random situation	15 (50%)	12 (40%)

As shown in Table 5.21, 50% and 40% of students' responses in the CCS and CPS classes were, respectively, found in the null model state (random response situation) which again showed that the CPS was a better approach than the CCS in changing the students' response states from low null model state to medium response states.

5.3.3 Effectiveness of Cognitive Perturbation using Simulations

The scores of the two treatment groups, the CCS and CPS classes, were compared by using one way analysis of covariance (ANCOVA). This analysis was done twice on two different quantitative scores, the DEEM and CM scores, that were meant for comparison of the results.

5.3.3.1 Analysis of Covariance on Diagnostic Exam of Electricity and Magnetism the Students' Scores

A one way between groups ANCOVA on the modified DEEM post-test scores, with pre-test scores as covariate, was used to analyze if there was any significant difference between the results of the two treatments. The students' pre and post scores on the modified DEEM were shown in Table 5.22. Initially, 45 students wrote the DEEM pre test; while 40 students wrote the post test and 39 students participated in both pre and post tests.

Table 5. 22: Pre and post intervention scores of the students in the CCS and CPS classes

Code	Pre DEEM Score	Post DEEM Score	Class
ST01	16.70	33.33	CPS
ST02	23.30	-	CPS
ST03	26.70	50.00	CPS
ST04	26.70	36.67	CPS
ST05	20.00	-	CPS
ST06	20.00	40.00	CPS
ST07	26.70	26.67	CPS
ST08	46.70	50.00	CPS
ST09	30.00	63.33	CPS
ST10	10.00	43.33	CPS
ST11	33.30	50.00	CPS
ST12	10.00	33.33	CPS
ST13	20.00	36.67	CPS
ST14	33.30	30.00	CPS
ST15	26.70	43.33	CPS
ST16	26.70	36.67	CPS
ST17	20.00	30.00	CPS
ST18	30.00	40.00	CPS
ST19	23.30	46.67	CPS
ST20	16.70	-	CPS
ST21	33.30	23.33	CPS
ST22	30.00	30.00	CPS
ST23	16.70	30.00	CPS
ST24	26.70	33.33	CCS
ST25	20.00	43.30	CCS
ST26	16.70	-	CCS
ST27	23.30	-	CCS
ST28	26.70	23.30	CCS
ST29	13.30	-	CCS
ST30	26.70	56.70	CCS
ST31	-	40.00	CCS
ST32	26.70	33.30	CCS
ST33	30.00	33.30	CCS
ST34	16.70	43.30	CCS
ST35	26.70	16.70	CCS
ST36	26.70	13.30	CCS
ST37	30.00	36.70	CCS
ST38	30.00	33.30	CCS
ST39	20.00	20.00	CCS
ST40	36.70	33.30	CCS
ST41	13.30	30.00	CCS
ST42	30.00	33.30	CCS

ST43	26.70	40.00	CCS
ST44	23.30	33.30	CCS
ST45	36.70	20.00	CCS
ST46	40.00	23.30	CCS

The outputs from ANCOVA were assessed by taking the following three conditions into account namely descriptive statistics, measuring the reliability of the covariate and the Levene's test of equality of error variances:

First, the descriptive statistics of the students' scores were analyzed and presented (see Table 23).

Table 5. 23: Descriptive statistics of students' score on the DEEM test

Dependent Variable: Post DEEM test score

CPS and CCS classes	Mean	Std. Deviation	N
CCS	31.56	10.51	19
CPS	38.67	9.88	20
Total	35.21	10.68	39

In relation to the quasi experimental design of this study, the main assumptions for using one-way ANCOVA were also checked. The first condition fulfilled for using ANCOVA was measuring the covariate prior to the intervention or experimental manipulation (Pallant, 2007). This was done to reduce interaction effects between the covariate (pre test score) and the dependent variable (post test score).

The second condition fulfilled before running ANCOVA was measuring the reliability of the covariate. Accordingly, the reliability of the DEEM pre test was checked using the Kuder Richardson-21 estimation (KR-21= 0. 86), which was an acceptable value for both individual and group testing (see Section 3.6.1).

The third condition needed prior to running ANCOVA was checking the Levene's test of equality of error variances (Pallant, 2007). This condition was checked which showed that the assumption of equality of variance was not violated because the significance value was 0.978 which was greater than 0.05 (see Table 5.24). In other words, homogeneity of error variances was not violated because the variability of scores for each of the groups was equal.

Table 5. 24: Levene's Test of Equality of Error Variances across groups

Dependent Variable: Post DEEM test score

F	df1	df2	Sig.
.001	1	37	0.98

Hence, a one-way between groups ANCOVA was conducted to compare the effectiveness of two different interventions designed to change students' alternative conceptions in the concepts of EPE and EMI. The independent variable was the type of intervention (CCS, CPS) and the dependent variable was students' scores on post DEEM test. The students' scores on pre DEEM test was used as the covariate in this analysis. After adjusting for the pre intervention scores using ANCOVA, there was a significant difference between the two intervention groups on the post test scores on the DEEM test, (1, 36) = 4.66, p=0.04 (see Table 5. 25). In other words, in changing the students' alternative conceptions to the scientific conceptions the CPS classes was statistically more significant than the CCS classes.

Table 5. 25: Between- Subjects Effects: Tests between the CCS and CPS Effects

Dependent Variable: Post DEEM test score

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	496.78(a)	2	248.39	2.33	0.11	0.12
Intercept	3435.25	1	3435.25	32.25	0.00	0.47
Pre DEEM	5.36	1	5.36	0.05	0.82	0.00
Class	496.75	1	496.75	4.66	0.04	0.12
Error	3834.89	36	106.53			
Total	52672.53	39				
Corrected Total	4331.66	38				

5.3.3.2 Analysis of Covariance on Students' Concept Maps Scores

A one-way between groups ANCOVA on the CM post-test scores, with CM pre-test scores as covariate, was used to analyze if there was any significant difference between the treatments. The students' CM pre and post scores were shown in Table 5.26. In this case, 34 students participated in both pre and post tests.

Table 5. 26: Students pre and post CM scores

Code	Rater1	Rater2	average	Rater1	Rater2	average	Class
	100%	100%	100%	100%	100%	100%	Class
CPS1	12.5	18.75	**15.63**	25.00	25.00	**25.00**	**CPS**
CPS2	6.25	12.5	**9.38**	25.00	31.25	**28.13**	**CPS**
CPS3	6.25	12.5	**9.38**	18.75	12.50	**15.63**	**CPS**
CPS4	6.25	6.25	**6.25**	31.25	31.25	**31.25**	**CPS**
CPS5	12.5	6.25	**9.38**	37.50	25.00	**31.25**	**CPS**
CPS6	6.25	6.25	**6.25**	31.25	18.75	**25.00**	**CPS**
CPS7	12.5	6.25	**9.38**	37.50	31.25	**34.38**	**CPS**
CPS8	12.5	12.5	**12.50**	37.50	37.50	**37.50**	**CPS**
CPS9	12.5	12.5	**12.50**	18.75	25.00	**21.88**	**CPS**
CPS13	6.25	0	**3.13**	12.50	18.75	**15.63**	**CPS**
CPS15	31.25	37.5	**34.38**	56.25	50.00	**53.13**	**CPS**
CPS16	6.25	18.75	**12.50**	18.75	18.75	**18.75**	**CPS**
CPS17	6.25	18.75	**12.50**	12.50	18.75	**15.63**	**CPS**
CPS18	6.25	6.25	**6.25**	18.75	25.00	**21.88**	**CPS**
CPS19	12.5	6.25	**9.38**	43.75	37.50	**40.63**	**CPS**
CPS20	6.25	0	**3.13**	12.50	25.00	**18.75**	**CPS**
CPS21	6.25	6.25	**6.25**	18.75	31.25	**25.00**	**CPS**
CPS23	0	6.25	**3.13**	18.75	18.75	**18.75**	**CPS**
CCS28	6.25	0	**3.13**	18.75	25.00	**21.88**	**CCS**
CCS30	12.5	6.25	**9.38**	12.50	12.50	**12.50**	**CCS**
CCS32	18.75	18.75	**18.75**	6.25	12.50	**9.38**	**CCS**
CCS33	18.75	6.25	**12.50**	12.50	25.00	**18.75**	**CCS**
CCS34	25	25	**25.00**	31.25	25.00	**28.13**	**CCS**
CCS35	6.25	0	**3.13**	31.25	25.00	**28.13**	**CCS**
CCS36	6.25	12.5	**9.38**	6.25	25.00	**15.63**	**CCS**
CCS38	18.75	25	**21.88**	25.00	18.75	**21.88**	**CCS**
CCS39	6.25	0	**3.13**	12.50	12.50	**12.50**	**CCS**
CCS40	0	6.25	**3.13**	18.75	12.50	**15.63**	**CCS**
CCS41	18.75	12.5	**15.63**	37.50	37.50	**37.50**	**CCS**
CCS42	18.75	12.5	**15.63**	18.75	18.75	**18.75**	**CCS**
CCS43	6.25	6.25	**6.25**	12.50	18.75	**15.63**	**CCS**
CCS44	25	25	**25.00**	31.25	37.50	**34.38**	**CCS**
CCS45	18.75	12.5	**15.63**	25.00	12.50	**18.75**	**CCS**
CCS46	18.75	12.5	**15.63**	12.50	18.75	**15.63**	**CCS**

Similar to the previous analysis in section 5.3.3.1, the conditions which helped in interpreting the output from ANCOVA were checked. First, the descriptive statistics of the students' CM scores were analyzed and presented (see Table 5. 27).

Table 5. 27: Descriptive statistics of students' scores on CM

Dependent Variable: post CM score

Class	Mean	Std. Deviation	N
CC	20.32	7.99	16
CP	26.57	10.07	18
Total	23.62	9.55	34

Then, the main assumptions for using one-way ANCOVA were also verified. The first condition fulfilled for using ANCOVA was measuring the covariate prior to the intervention or experimental manipulation (Pallant, 2007). This was done to reduce interaction effects between the covariate (pre test score) and the dependent variable (post test score).

The second condition to confirm before running ANCOVA was measuring the reliability of the covariate. Accordingly, a reasonable result of inter-rater reliability (0.71) of the pre CM score was estimated (see Section 3.6.3).

The third condition was the Levene's test of equality of error variances which showed that the assumption of equality of variance was not violated because the significance value was 0.543 which was greater than 0.05 (see Table 5. 28). In other words, homogeneity of error variances was not violated because the variability of scores for each of the groups was equal.

Table 5. 28: Levene's Test of Equality of Error Variances across groups

Dependent Variable: post CM score

F	df1	df2	Sig.
0.38	1	32	0.54

Hence, a one-way between groups ANCOVA was conducted to compare the effectiveness of the two different interventions designed to change students' alternative conceptions in the concepts of EPE and EMI. The independent variable was the type of intervention (CCS, CPS) and the dependent variable was the students' CM post scores. The students' scores on their pre CM was used as the covariate in this analysis. After adjusting for the pre intervention scores using ANCOVA, there was significant difference between the two intervention groups on the CM post intervention scores, (1, 31) = 8.33, p=0.007 (see Table 5. 29). In other words, in changing the alternative conceptions of the students, the CPS class was statistically more significant than the CCS classes.

Table 5. 29: Between- Subjects Effects: Tests between the CCS and CPS Effects

Dependent Variable: post CM score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1075.51(a)	2	537.76	8.61	.001	0.36
Intercept	2456.33	1	2456.33	39.33	.000	0.56
Pre	744.69	1	744.69	11.92	.002	0.28
class	520.35	1	520.35	8.33	.007	0.21
Error	1936.08	31	62.45			
Total	21986.95	34				
Corrected Total	3011.59	33				

5.3.3.3 Average Normalized Gain

Average normalized gain (Hake, 1998) (ranging from 0 to 1) (see Section 3.7.2.4) from pre to post scores in the modified DEEM was analyzed to characterize and compare students' conceptual change of both treatment classes.

Table 5. 30: Average normalized gain

	CCS Class	CPS Class
DEEM Score	<g>=0.05	<g>=0.17
CM Score	<g>=0.08	<g>=0.18

The average normalized gain of scores was found greater in the CPS class than in the CCS class in both the DEEM test and the CM data (see Table 5.30). This showed that the CPS approach was more effective than the CCS to change the students' alternative conceptions.

However, the normalized average gains of both classes were less than 0.3, which was found in the low level according to physics education researchers (Hake, 1998; Coletta, Phillips & Steinert, 2007). The details of this categorization were discussed in section 3.7.2.4. This means that though the CPS approach was statistically effective in comparison to the CCS there was no significant change observed in students' conceptual knowledge. The average post test scores in both classes were less than 40% which was found in the low score level. The possible reason for this low average normalized gain was that the student conceptual knowledge level was low which limited their interactive engagement in the conceptual learning.

5.4 Triangulation of the Post Intervention Results

Similar to triangulation of the pre intervention results (see Section 4.5) which were done to strengthen the validity and reliability of the results, , four types of post intervention results were presented and triangulated based on the data collected with the FGD, CM and modified DEEM. These were the qualitative results of data collected with the FGD, the qualitative and quantitative results of data collected with the CM and the quantitative results of data collected with the DEEM test. To this end, the four post intervention results were triangulated in three ways. These were triangulation of: the qualitative results of FGD and CM data, the quantitative results of the modified DEEM test and CM data, and the qualitative and the quantitative results.

5.4.1 Triangulation of Qualitative Results

The qualitative analyses of data from the FGD and CM were mainly to answer the second research question about the categories of students' conceptions after intervention with regards to the concepts of EPE and EMI. Accordingly, as discussed in section 4.5.1, the results of the two qualitative data (the results of individual-based CM data and group-based FGD data) were triangulated at categorical level to ensure validity and reliability of the existed categories of the students' conceptions after intervention.

In the post intervention results from both FGD and CM data, in total, six categories of students' alternative conceptions and three categories of conceptual knowledge existed in the concepts of EPE and EMI. These six categories of the students' alternative conceptions were naïve physics, lateral alternative conceptions, ontological alternative conceptions, P-Primes (Ohm's P-Primes), mixed alternative conceptions and loose ideas. The three categories of conceptual knowledge were hierarchical conceptual knowledge, relational conceptual knowledge and scientific model. Among these categories of the students' conceptions, four categories of alternative conceptions (naïve physics, lateral alternative conceptions, ontological alternative conceptions, mixed alternative conceptions) and two categories of conceptual knowledge (hierarchical and relational) were commonly developed from the two qualitative analyses (see Tables 5.31 & 5.32). The p-primes emerged as an inclusive category in the results of CM data while the Ohm's p-primes as a category in the results of FGD data (see Tables 5.4 & 5.13). This means that the Ohm's p-prim was considered as a subcategory in the CM data. In addition, the scientific model as a category of conceptual knowledge was developed only from the students CM data (see Table 5.17). Based on these results, it could be confirmed that the results from the two qualitative methods mostly complemented each other.

Tables 5.31 and 5.32 illustrate triangulation of the qualitative results from the FGD and CM data in terms of number of students' conceptions in the categories and extensiveness of the categories. In addition, these tables were used to compare the number of students' conceptions and the extensiveness of the categories in both the CCS and CPS classes.

Table 5. 31: Triangulation of categories of conceptions in terms of their distribution

Category	**CCS Class**		**CPS Class**	
	Distribution of students' conceptions in EPE &EMI			
	FGD	**CM**	**FGD**	**CM**
Alternative Conceptions	**36(68%)**	**44(69%)**	**24(52%)**	**35(56%)**
Naïve physics	21	13	10	15
Lateral	7	15	2	11
Ontological	2	6	4	3
P-primes	-	8	-	5
Ohm's p-primes	3	-	2	-
Mixed	2	2	6	1
Loose ideas	1	-	-	-
Conceptual Knowledge	**17 (32%)**	**20(31%)**	**22(48%)**	**27(44%)**
Hierarchical	6	5	5	5
Relational	11	14	17	15
Scientific model	-	1	-	7

In the CCS class, the percentage distribution of alternative conceptions from the FGD and CM data were, respectively, 68% and 69%; while in the CPS class, the percentage distribution of alternative conceptions from the FGD and CM data were, respectively, 52% and 56% (see Table 5.31). On the contrary, in the CCS class, the percentage distribution of the students conceptual knowledge from the FGD and CM data were, respectively, 32% and 31%; while in the CPS class, the percentage distribution of the students conceptual knowledge from the FGD and CM data were, respectively, 48% and 44% (see Table 5.31). These results showed that the CPS was a better approach than the CCS in reducing the number of alternative conceptions and increasing the number of conceptual knowledge of the students. In other words, there was a shift in students' conceptions from alternative conceptions to scientific conceptions which was higher in the CPS class than in the CCS class because the total number of conceptual knowledge in both the concepts of EPE and EMI were more in the CPS class than in the CCS class.

In the CCS class, the percentage extensiveness of alternative conceptions in the categories from the FGD and CM data were, respectively, 62% and 51%; while in the CPS class, the percentage extensiveness of alternative conceptions from the FGD and CM data were, respectively, 46% and 41% (see Table 5.32). In contrast, in the CCS class, the percentage extensiveness of the students conceptual knowledge from the FGD and CM data were, respectively, 38% and 49%; while in the CPS class, the percentage extensiveness of the students conceptual knowledge from the FGD and CM data were, respectively, 54% and 49% (see Table 5.32). These results again showed that the CPS was a more appropriate approach than the CCS in reducing extensiveness of students' alternative conceptions and increasing the extensiveness of conceptual knowledge of the students.

Table 5. 32: Triangulation of categories of students' conceptions in terms of their extensiveness

Category	**CCS Class**		**CPS Class**	
	Extensiveness of students' conceptions in EPE &EMI			
	FGD	**CM**	**FGD**	**CM**
Alternative conceptions	**45 (62%)**	**55 (51%)**	**32 (46%)**	**61(41%)**
Naïve physics	27	18	13	30
Lateral	10	21	2	22
Ontological	2	6	4	4
P-Primes	-	8		5
Ohm's P-Primes	3		3	-
Mixed	2	2	10	1
Loose ideas	1	-	-	-
Conceptual knowledge	**27(38%)**	**53(49%)**	**38 (54%)**	**88 (59%)**
Hierarchical	9	17	8	28
Relational	18	35	30	42
Scientific model	-	1	-	18

5.4.2 Triangulation of Quantitative Results

After intervention, the triangulation of the quantitative results was also done using the results from ANCOVA and the average normalized gain on the two quantitative data sources for this study.

An ANCOVA was separately conducted to compare the effectiveness of the CCS and CPS using the students' scores on the DEEM test and CM data. As a result, there was significant difference between the two intervention groups on the post test scores on the DEEM test, (1, 36) = 4.663, p=0.038 (see Table 5. 25) and similarly, on the CM test, (1, 31) = 8.332, p=0.007 (see Table 5. 29). These results showed that in changing the alternative conceptions of the students towards scientific conceptions the CPS was statistically more significant than the CCS.

In addition, the average normalized gains (see Table 5.30) from pre to post scores in the modified DEEM were, respectively, 0.05 and 0.17 for the CCS and CPS classes. Similarly, these values from pre to post scores in the CM were, respectively, 0.08 and 0.18 for the CCS and CPS classes. These results indicated that the average normalized gains from the two different quantitative data were comparable and were more in the CPS class than in the CCS class (see Table 5.30). This implied that the CPS strategy was more effective than the CCS strategy to change the students' alternative conceptions.

5.4.3 Triangulation of Qualitative and Quantitative Results

In both effectiveness measures of quantitative analyses, it was shown that the CPS was statistically significant than the CCS in enhancing conceptual learning in the concepts of EPE and EMI (see Tables 5.25 & 5.29). Similarly, in both qualitative analyses of FGD and CM data, on the one hand, the percentage distribution of alternative conceptions and extensiveness of the categories of alternative conceptions were more in the CCS than in the CPS; on the other hand, the percentage distribution of the students conceptual knowledge and extensiveness of the categories of their conceptual knowledge were more in the CPS than in the CCS (see Table 5.31 & 5.32). Hence, these qualitative and quantitative results were in agreement to each other which the triangulation enabled to clarify one form of the results (qualitative or quantitative) in terms of the other.

Moreover, as illustrated in Table 5.20, the categorization of quantitative students' scores in the CCS and CPS classes indicated that 70% of the students' responses in the CCS class and 40% of the students' responses in the CPS class were found in the low score level. In the medium score level, 26.7% of the students' responses in the CCS class and 56.7% of the students' responses in the CPS class were found (see Table 5.20). These results were in agreement with the comparative qualitative results of the percentages of the number and extensiveness of conceptual knowledge categories in both treatment classes (see Tables 5.31 & 5.32). This means that the percentages of the number and extensiveness of the categories of the conceptual knowledge were more in the CPS class than in the CCS class.

5.5 Discussion

The categories of students' conceptions existing in the pre intervention remained persist also in the post intervention but with different distribution and extensiveness of conceptions in the categories. In general, the number of alternative conceptions and extensiveness of categories of alternative conceptions became less in the post intervention than in the pre intervention results. However, in the post intervention results, significant difference was obtained between the two treatment classes' distributions of alternative conceptions and conceptual knowledge. This means that the total number of alternative conceptions in the categories was found less while the total number of conceptual knowledge was found greater in the CPS class than in the CCS class. Similarly, the extensiveness of all alternative conceptions in the categories were found less in the CPS class than in the CCS class but the extensiveness of all conceptual knowledge categories were found greater in the CPS class than in the CCS.

However, such exceeding pattern of the number and extensiveness of alternative conceptions in the CCS were not held true in all categories. Hence, the following were discussed based on summarized results given in Tables 5.31 & 5.32:

- The number and extensiveness of naïve physics, lateral alternative conceptions and P-Primes (Ohm's P-Primes) were less in the CPS class than in the CCS class;
- The number and extensiveness of ontological alternative conceptions were slightly greater in the CPS class than in the CCS class;

- The mixed alternative conceptions in terms of their number and extensiveness were found greater in CPS class than in CCS class (see Table 5.5);
- The extensiveness of students' hierarchical conceptual knowledge was slightly greater in the CPS class than in the CCS class;
- The relational conceptual knowledge was the category in which the two treatment classes showed a significant difference in terms of their number and extensiveness. This means that the number and extensiveness of relational conceptual knowledge were more in the CPS class (17, 30) than in CCS class (11, 18); and
- Scientific model was more identified in the CPS class than in the CCS class because the number and extensiveness of scientific model depicted was more in the CPS class (7, 18) than in the CCS class (1, 1) (see Tables 5.31 & 5.32). This showed that the CPS strategy was more effective than the CCS strategy to develop students' knowledge of representing scalar and vector fields, such as representation of electric and magnetic fields and equipotentials with field lines in abstract concepts of electricity and magnetism.

Therefore, based on the above discussed points, it could be confirmed that the CPS strategy was more effective than the CCS strategy in reducing the number and extensiveness of naïve physics, lateral alternative conceptions and P-Primes (Ohm's P-Primes) and increasing the number and extensiveness of conceptual knowledge categories. In addition, the number and extensiveness of mixed alternative conceptions were also more in the CPS class than in the CCS class which was in agreement with the quantitative students' responses state categorization (see Table 5.21). This means that the CPS approach was more effective than the CCS approach in changing the students' alternative conceptions from a null model to two models conceptions.

A one-way between groups ANCOVA was conducted to compare the effectiveness of the two different interventions designed to change students' alternative conceptions in the concepts of EPE and EMI. The students' post intervention scores on the modified DEEM and concept maps were independently used to compare the effects of the intervention. As a result, there was statistically significant difference between the two intervention groups on the post test scores on the DEEM test, $(1, 36) = 4.66$, $p=0.04$ (see Table 5. 25) and on the CM test, $(1, 31) = 8.33$, $p=0.007$ (see Table 5. 29) which showed that the CPS was more effective than the CCS in changing the alternative conceptions of the students towards scientific conceptions.

In addition, the average normalized gain of scores was found greater in the CPS class than in the CCS class in both the DEEM test and the CM data (see Table 5.30). This also showed that the CPS approach was more effective than the CCS to change the students' alternative conceptions. However, the normalized average gains of both classes were less than 0.3, which was found in the low level according to physics education researchers (Hake, 1998; Coletta, Phillips & Steinert, 2007). This means that though the CPS approach was statistically effective in relation to the CCS there was no significant conceptual knowledge gain attained by the students because the average post test scores in both classes were less than 40% which was found in the low score level. The possible reason for this low average normalized gain was that the students' conceptual knowledge level in the concepts of EM was low which limited their interactive engagement in the learning of the concepts.

This study was not intended to measure the intermediate conceptions which were the learning progression that students follow to attain a target conception developed during the process conceptual change. However, supplementary were annexed (Appendices H & I) to show readers the details of the learning progression of the students. Undoubtedly, this study relied on pre-post assessments to measure the effectiveness of the two conditions.

Although the use of group work when five to six students sharing computers might have advantages for concepts learning, it was thought disadvantageous because it might limit hands-on learning as all the group members could not run the simulation at a time. Besides, the short period of eight hours dedicated to the intervention of two broad conceptual areas of physics might have contributed to the low learning gain in conceptual knowledge. Moreover, as discussed in Section 1.8, most of the students assigned to study physics are those less scoring who lack interest to study physics. This also partly can explain their poor performance in the study tasks that their alternative conceptions were considerably more extensive than their conceptual knowledge.

5.6 Summary of the Chapter

This chapter presented post intervention results on categorization of students' conceptions and effectiveness of the CPS in relation to the CCS to enhance conceptual change.

The *group-based data* from the FGD and the *individual-based data* from the CM were independently analyzed using the framework thematic analysis to categorize the students' post intervention conceptions. Almost all the categories of students' conceptions in the pre intervention persisted in the post intervention, but there were changes in the distribution and extensiveness of their conceptions in the categories. In addition, the percentage of occurrences of the students' conceptions in both the CCS and CPS classes showed differences which were compared. This means, the number of alternative conceptions and extensiveness of categories of the alternative conceptions was lesser in the CPS class than in the CCS class while number of the students' conceptual knowledge and their corresponding extensiveness were more in the CPS class than in the CCS class. Also, the diversification of the students' alternative conceptions was lesser in the CPS class than in the CCS class. These indicated that students' conceptual knowledge were more consistent in the CPS class than in the CCS class.

From the quantitative concentration analysis, it was found that the CPS was a better approach than the CCS in changing the students' response states from low null model state to medium response states. In addition, the outputs from ANCOVA were assessed on post test DEEM and CM scores independently to compare the effectiveness of two different interventions, CCS and CPS, designed to change students' alternative conceptions in the concepts of EPE and EMI. In both cases significant differences between the two intervention groups on the post test scores were obtained in favoring the CPS. Moreover, the average normalized gain of scores was found greater in the CPS class than in the CCS class in both quantitative scores which also showed that the CPS was more effective than the CCS to change the students' alternative conceptions to scientific conceptions.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This study was to investigate Ethiopian physics undergraduate students' conceptual change in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) by supporting their learning through Cognitive Perturbation using interactive physics simulations. The study encompassed two phases. The first phase was the categorization of the students' conceptions in the concepts of EPE and EMI based on the students' epistemological and ontological descriptions of the concepts. The second phase was studying the impact of cognitive perturbation through physics interactive simulations (CPS) in relation to cognitive conflict through physics interactive simulations (CCS).

In relation to the problem investigated, the literature from students' conceptions and conceptual change in electricity and magnetism (see Section 2.2 & 2.4.3), categories of students' conceptions (see Section 2.3), the classical conceptual change model and its limitations(see Section 2.4.1), the role of cognitive conflict strategy in conceptual change (see Section 2.4.2), the role of computer interactive simulations in conceptual change (see Section 2.4.5), the need for cognitive perturbation strategy (see section 2.4.4) and the role of concept maps in conceptual change (see section 2.4.6) were reviewed. The literature review helped the researcher to identify the problem and design the research questions.

Accordingly, the research questions addressed in this study were:

1. What are the categories of students' conceptions in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) before intervention?
2. What are the categories of students' conceptions in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI) after intervention?
3. How significant is conceptual change through cognitive perturbation using simulations (CPS) as compared to cognitive conflict using simulations (CCS) in the concepts of electric potential and energy (EPE) and electromagnetic induction (EMI)?

The theoretical framework used for this study was the constructivist theory of learning (von Glaserfeld & Steffe, 1991; Driver, et al., 1994) which also helped the researcher in the design of the study. According to this theory, the students' conceptions were viewed as their personal understanding of the concepts under investigation from their epistemological and ontological descriptions of concepts (Abell & Eichinger, 1998; Treagust & Duit, 2008).

This study employed a *quasi-experimental design* and used *concurrent mixed methods* research to conduct an in depth investigation of the students' conceptions and conceptual change in the selected concepts of electricity and magnetism. A pragmatic approach (Doyle et al., 2009) was followed, which involved concurrent but separate collection and analysis of multiple types of data which were then triangulated for interpretation of the results.

The research sample included 45 first year physics undergraduate students (aged between18 to 23) who were registered for the course electricity and magnetism in the year 2011 at the Ambo University in Ethiopia. The students were randomly assigned into two lab groups (group A and group B) by the Department of Physics (see Section 3.3). From these existing two lab groups for the course, control and experimental classes were randomly assigned into cognitive conflict using simulation (CCS) and cognitive perturbation using simulation (CPS), respectively. The students in the research group were treated as autonomous whose decisions on whether or not to participate in research was respected and not dominated by the researcher (see Section 3.6).

This study employed a number of different data collection instruments including conceptual tests, focus group discussions (FGD) and concept maps (CM). The tests were the CSEM (Conceptual Survey of Electricity and Magnetism) and a modified DEEM (Diagnostic Exam of Electricity and Magnetism) developed by Maloney et al. (2001) and Marx (1998), respectively. The CSEM was meant not to collect data for the research questions, but used to study the students' prior conceptual knowledge level and form homogenous ability focus groups for discussions. The different data collection instruments (the modified DEEM, FGD and CM) assisted to obtain an in-depth and close understanding of students' conceptions and the process of conceptual change in the concepts of EPE and EMI. These conceptual areas of electricity and magnetism were selected because they challenge students across different countries (Planinic, 2006; Saglam & Millar, 2006) and their alternative conceptions have not been well studied compared to classical mechanics and DC circuits. In addition, there are recommendations for the need to undertake in-depth studies by taking a few conceptual areas of EM using multi methods (Chabay & Sherwood, 2006; Ding, Chabay, Sheewood, & Beichner, 2006; Maloney et al., 2001; Planinic, 2006). Experts' consciences and statistical approximations were, respectively, used to check validity and reliability of the research instruments. The reliability of the modified DEEM test and the students' CM were approximated with the KR-21 and inter-rater reliability, respectively, in which the results were found suitable for both individual and group tests.

A five stage framework analysis method (Rabiee, 2004; Ritchie & Spencer, 1994) which involved familiarization, identifying a thematic framework, coding, charting and interpretation was separately used for focus groups discussions and concept maps qualitative data analyses in both the pre and post intervention study. The specific reason for adapting this method was its characteristic feature that allows themes to develop both from the literature and from the discussion or depiction of the research participants (Rabiee, 2004). The framework analysis was used in each of the *group-based data* (data collected with the focus groups discussions) and *individual-based data* (data collected with the students' concept maps) to categorize the students' conceptions.

Concentration analysis (Bao & Redish, 2001) was used to analyze the students' response to the multiple-choice modified DEEM test and find patterns in the students' alternative conceptions and conceptual knowledge in pre and post treatments. In this analysis, characterization and categorization of students' responses were done in which the students' response patterns were formed by combining both their responses concentration scores and concentration factors. Consequently, three-levels coding (Bao & Redish, 2001) were used to categorize students' response states (see Table 3.2).

The qualitative analyses of FGD and CM data were used to answer the first and the second research questions while quantitative analyses of data collected by the modified DEEM and students' concept maps were used to answer the third research question. In addition, the results of the quantitative analyses of both concept maps and the modified DEEM data were used to supplement the qualitative analyses. Moreover, the qualitative results helped to understand and explain the quantitative results.

Analysis of covariance was conducted on the data which were collected by the modified DEEM test and the students' CM in order to compare the results. ANCOVA on the modified DEEM post-test scores, with pre-test scores as covariate, was used to analyze if there was any significant difference between the treatments. Likewise, the difference between the averages of post CM scores of both treatment classes were analyzed using ANCOVA with pre CM scores as covariate to examine the effectiveness of the CPS to the CCS. In addition, average normalized gain <g> (Hake, 1998) of the two quantitative data (the modified DEEM and the CM) from pre to post scores were analyzed to characterize and compare students' conceptual change of both treatment groups.

The results of this study were presented in Chapters Four and Five, in which the pre and post intervention results were, respectively, analyzed and presented. The pre intervention findings were to answer the first research question while the post intervention findings were to answer the second and third research questions (see Sections 1.4 and 6.1). Then, the study came up with the following major findings.

1. The first research question investigated the categories of students' conceptions in the electric potential and energy (EPE) and electromagnetic induction (EMI) conceptual areas before intervention. From the analysis, six categories of alternative conceptions and two categories of conceptual knowledge were identified. Among these categories of alternative conceptions, four were presupposed categories based on the literature review namely naive physics, lateral alternative conceptions, ontological alternative conceptions and Ohm's p-primes (P-Primes) while the other two that emerged were termed mixed conceptions and loose ideas. In addition, the two categories of students' conceptual knowledge were diagnosed as *hierarchical* and *relational* conceptual knowledge (see Section 2.3.2). Almost all the identified categories of the students' conceptions in the analyses of both qualitative data were similar, except the emergence of the p-primes as an inclusive category in the results of the CM data and the Ohm's p-primes as a category in the results of the FGD data. In the CM data results, the Ohm's p-prime was considered as a subcategory (see Tables 4.34 & 4.35).

   In the qualitative results of the pre intervention study, the extensiveness of the categories of alternative conceptions was greater than 80% while the extensiveness of categories of conceptual knowledge was less than 20% (see Table 4.35). This means that the extensiveness of conceptual knowledge in both the focus groups discussions and concept maps showed that the students' conceptual knowledge was low and they lacked in depth conceptual understanding of concepts in EPE and EMI.

This categorization of students' conceptions in the concepts of electricity and magnetism can contribute to the current literature because earlier studies in students' conceptual change were mainly focused on the identification of alternative conceptions based on epistemological perspectives of students' conceptions (McDermott & Redish, 1999; Soto-Lombana, Otero & Sanjosé, 2005). This means that the results of this study are believed to promote the sole identification of alternative conceptions using epistemological perspective, which have been done for the last 30 years, towards categorization of conceptions in which inclusive epistemological and ontological perspectives of conceptions were used. This is the first major contribution of this study towards the theory of conceptual change.

Although this study was not intended to settle the dispute between the coherence and fragmentation of alternative conceptions (Clark et al. 201; diSessa, et al., 2004; Elby 2010; Ioannides & Vosniadou, 2002), however, the diagnosed alternative conceptions are in favor of fragmentation over coherence perspectives because the diagnosed alternative conceptions are diversified, inconsistent within and across the categories and are less frequent and less extensive (see Sections 4.1.4, 4.2.4 & 4.5.3 and tables 4.15 & 4.28).

Concentration analysis was conducted on the data of the DEEM test to categorize the students' responses states (see Section 4.3.1) by using three-levels coding and categorization. Accordingly, the categorization indicated that the students' response states were mainly found in the low non-modal random response state. The quantitative results were also compared using the average scores of the students in the modified DEEM test and their CM. In the DEEM test data, the average concentration score of the students was approximately 0.26 (see Table 4.30). According to Bao and Redish (2001), this score was found in the low score state (0.0 to 0.4) (see Table 3.9). In the data of the concepts maps, the students' average score was only 11%, which was also low (see Table 4. 32). In addition, the students' answers in their CM were more of simple proportional relations (simple relational conceptual knowledge) (see Section 4.4). Moreover, the students' answers in their CM lacked cross-links and examples that were believed to measure their in-depth conceptual understanding (see Section 2.4.6). Therefore, the pre intervention quantitative results of the modified DEEM test and CM data indicated that the students' conceptual knowledge in the concepts of EPE and EMI was low. These results are in agreement with the finding of Planinic (2006) which shows that the conceptual areas EMI and EPE are among the most difficult conceptual areas of electricity and magnetism.

2. The second research question which was in the post intervention study was about categorization of students' conceptions in the concepts of EPE and EMI after intervention (see Sections 1.4 and 6.1). In this post intervention analyses, similar to that of pre intervention, both the g*roup-based data* and *individual-based data* were analyzed separately using the framework thematic analysis (see Section 3.7.1). The categorization of students' conceptions was presented with respect to the two treatment classes, the CCS and CPS classes. Accordingly, except the scientific model category which was identified extensively in the CPS class, almost all the categories of students' conceptions which existed in the pre intervention study persisted also in the post intervention study (see Sections 5.1, 5.2 & 5.2.2.3). However, after intervention, the percentage distributions of the students' conceptions and their extensiveness in both the CCS and CPS classes showed differences.

   In the CCS class, the percentage distribution of alternative conceptions from the FGD and CM data were, respectively, 68% and 69%; while in the CPS class, the percentage distribution of alternative conceptions from the FGD and CM data were, respectively, 52% and 56% (see Table 5.31). On the contrary, in the CCS class, the percentage distribution of the students conceptual knowledge from the FGD and CM data were, respectively, 32% and 31%; while in the CPS class, the percentage distribution of the students conceptual knowledge from the FGD and CM data were, respectively, 48% and 44% (see Table 5.31). These results showed that CPS is a better approach than CCS in reducing the number of alternative conceptions and in increasing the students' conceptual knowledge. In other words, there was a change in students' conceptions from alternative conceptions to conceptual knowledge which was higher in the CPS class than in the CCS class because the percentage distribution of conceptual knowledge in both the concepts of EPE and EMI were more in the CPS class than in the CCS class.

   Besides, in the CCS class, the percentage extensiveness of alternative conceptions in the categories from the FGD and CM data were, respectively, 62% and 51%; while in the CPS class, the percentage extensiveness of alternative conceptions from the FGD and CM data were, respectively, 46% and 41% (see Table 5.32). In contrast, in the CCS class, the percentage extensiveness of the students conceptual knowledge from the FGD and CM data were, respectively, 38% and 49%; while in the CPS class, the percentage extensiveness of the students conceptual knowledge from the FGD and CM data were, respectively, 54% and 59% (see Table 5.32). These results again showed that CPS is a more suitable approach than CCS in reducing the extensiveness of alternative conceptions and in increasing the extensiveness of conceptual knowledge of these students.

The aforementioned two results are in line with the earlier studies (Limon, 2001; Zohar & Aharon-Kravetsky, 2005) about the cognitive conflict approaches' hindrance effect on progress of students with low academic achievement (see Section 2.4.2). In addition, studies (e.g. Chinn & Brewer, 1993) show that students' responses to scientific conceptions are influenced by their prior knowledge. That is, the students were having little or inconsistent conceptual knowledge in the concepts of EPE and EMI investigated in this study that the cognitive conflict had an insignificant effect in relation to the cognitive perturbation on students' concepts learning. Moreover, Lee and Byun (2012) show that in cognitive conflict, the most common responses of students indicate superficial conceptual change. As discussed in Section 2.4.2, this is because of the inconsistency of students' conceptions that are found at low levels and the wide cognitive gap that exists between their prior conception and scientific conception. As a result, the CCS becomes less effective than the CPS in these students' conceptual change of the concepts in EPE and EMI.

3. The third research question was about the effectiveness of the cognitive perturbation using simulation (CPS) and the cognitive conflict using simulation (CCS) to enhance students' conceptual change in the concepts of EPE and EMI (see Sections 1.4 & 6.1).

   A one-way between groups ANCOVA was separately conducted to compare the effectiveness of the CCS and CPS using the students' scores on the DEEM test and CM. A significant difference between the two intervention groups on the post test scores on the DEEM test, $(1, 36) = 4.66$, $p=0.04$ ($p < 0.05$) (see Table 5. 25) and similarly, on the CM test, $(1, 31) = 8.33$, $p=0.007$($p < 0.05$) (see Table 5. 29) was found. These results showed that the CPS was more effective than the CCS in changing the alternative conceptions of the students towards scientific conceptions.

In addition, the average normalized gains (see Table 5.30) from pre to post scores in the modified DEEM were, respectively, 0.05 and 0.17 for the CCS and CPS classes. Similarly, these values from pre to post scores in the CM were, respectively, 0.08 and 0.18 for the CCS and CPS classes. Although the CPS approach was statistically effective than the CCS approach, the students' scores after intervention were low in both treatment groups because the average normalized gain was by far less than 0.3 (see Section 5.3.3.3).

The students' alternative conceptions were found to be inconsistent in the concepts of EPE and EMI within and across the existing categories of alternative conceptions (see Tables 4.14 & 4.15 and 4.27 & 4.28). In addition, the comparison of the concentration factor and concentration deviation of the students' responses on the DEEM pre test items was conducted using paired samples t-test which showed insignificant statistical difference between the two concentrations of students' responses, that is, $t\ (29) = 1.99$, $p > 0.05$ (see Table 4.32). Moreover, both the concentration factor and the concentration deviation of the students responses to the DEEM test were found in the low null model state (see Table 4.30), which also indicated the inconsistency of the students responses. Therefore, the pre intervention quantitative and qualitative results confirmed that the students' conceptions were inconsistent in the concepts of EPE and EMI.

The average concentration score of the students on the DEEM pre test was approximately 0.26 which was found in the low score state (see Tables 3.9 & 4.31). In addition, the students' answers in their CM lacked cross-links and examples that were believed to measure their in-depth conceptual understanding (see Section 4.4). Hence, these results indicated that the students' conceptual knowledge in the concepts of EPE and EMI was low.

Therefore, based on the above discussed results, this study shows that for students with low conceptual knowledge and inconsistent alternative conceptions, like the concepts of EPE and EMI, the CPS is more effective than the CCS to progress their conceptual learning.

Earlier studies on students' conceptual change compared constructivist learning strategies with non constructivist learning strategies (traditional model of learning) (Baser, 2006; Baser & Geban, 2007; Rosen & Salomon, 2007) but this study compared the CCS and CPS, in which both were based on constructivist theory of learning (see Section 2.4.4). Although, the students in the CCS and CPS were treated differently (see Section 3.8.2 & 3.8.3 and Appendices H & I) the concepts thought and the simulations used were the same in both classes. In the CCS class, students' conceptions were demarcated as either alternative conceptions or scientific conceptions, but in the CPS class, intermediate conceptions which were the learning progression that students follow to attain a target conception during the learning process were considered in order to support them in changing of their alternative conceptions (Maloney & Siegler, 1993). This helped to identify the fact that students in the CCS class failed to make sense of the difference between alternative and scientific conceptions in the complex concepts of EPE and EMI and maintained their alternative conceptions after instruction. In addition, classroom social contexts were considered to support the students in the CPS class (see Appendix I). Therefore, conceptual change that involves evolutionary (gradually step by step) process of learning is found to be more appropriate than conceptual change that involves revolutionary (radical) process of learning for students with low conceptual knowledge and inconsistent alternative conceptions. This is another main contribution of this study to the theory of conceptual change in addition to the categorization of alternative conceptions.

The computer interactive physics simulations were intended to engage the students in both CCS and CPS classes into interactions and help them to visualize and understand the abstract concepts and phenomena in EM concepts. However, their low level conceptual knowledge impeded their learning and not to show significantly progressed conceptual change because their average normalized gains were low (less than 0.3 in both classes) (see Section 5.3.3.3). This showed that prior conceptual knowledge influences students' interactive engagement in conceptual learning.

6.2 Conclusions

Based on the findings of this study which were presented and discussed in Chapters 4 & 5 and then summarized in Section 6.1, conclusions are drawn in the subsequent paragraphs.

In the pre intervention categorization of students' conceptions in the concepts of electric potential and energy and electromagnetic induction, six categories of alternative conceptions and two categories of conceptual knowledge were identified (see Sections 4.1.1 & 4.2.1) which were complex and holistic in nature. Hence, the following conclusions are drawn from this categorization of students' conceptions.

- The existing categories have different distributions of the alternative conceptions;
- Across the different categories, a specific concept is found to have different forms of alternative conceptions;
- Within the categories, the students have multiple conceptions of specific concepts;
- The naïve physics and lateral alternative conceptions are found more extensive than the others;
- Alternative conceptions in both epistemological and ontological perspectives are comparable and considerable. This means that the extensiveness of naïve physics and P-Primes is comparable to the extensiveness of lateral and ontological alternative conceptions and they are also significant with respect to extensiveness of the others categories (see Tables 4.34 & 4.4).
- Across and within the categories, the students' conceptions are inconsistently diversified (see Tables 4.15 & 4.28);
- The percentage distribution of the extensiveness of alternative conceptions exceeds the percentage distribution of number of students' alternative conceptions in the categories, but for the conceptual knowledge the situation is reversed (see Tables 4.14 & 4.27).

In addition, post intervention categorization of students' conceptions in the concepts of electric potential and energy and electromagnetic induction were investigated. As discussed in Sections 5.1.1 and 5.2.1, almost all the pre intervention existing categories of students' conceptions persisted after the intervention but with different percentage of distributions of the conceptions and their extensiveness after intervention in both the CCS and CPS classes. Hence, the following conclusions were drawn from these results.

- The categories of the students' conceptions persist after intervention;
- Extensiveness of students' conceptual knowledge increases from less than 20% of pre treatments to more than 40% of after treatments;
- The extensiveness of students' conceptual knowledge was credibly higher in the CPS class (54% in FGD & 59% in CM) than in the CCS class (38% in FGD & 49% in CM);
- The naïve physics and relational conceptual knowledge categories are more extensive than the rest of the categories;

- Epistemological alternative conceptions are more extensively described than ontological alternative conceptions;
- The percentage distribution of the number of students' conceptions in the categories exceeds the percentage distribution of the extensiveness, but for the conceptual knowledge the situation is reversed.

The following conclusions were drawn based on the results of the third research question.

- For students with low conceptual knowledge and inconsistent alternative conceptions, the CPS approach is more effective than the CCS approach to change their alternative conceptions;
- The students' response states can be improved by the CPS approach rather than the CCS approach;
- Low pre scores of students have negative impact on conceptual change because they limit students' interactive engagement in the learning of concepts.

In general, this study used the epistemological and ontological descriptions of students' conceptions to categorize the students' descriptions of the concepts in EPE and EMI. However, if one of the perspectives, either epistemological or ontological, was preferred as a view of this study, then such a holistic categorization would not be investigated. For example, on the one hand, if the epistemological perspective was traced, then the dominant categories would be naïve physics and the Ohm's p-primes that could overlook the ontological and lateral alternative conceptions of the students. On the other hand, if the ontological perspective was traced, then the reverse would be the case. One of the bases for the dispute that exists on the structure of alternative conceptions is due to the fact that different theoretical framework are used by different researchers of alternative conceptions. Hence, a pragmatic inclusive perspective is helpful to study these complex and holistic classifications of students' conceptions.

6.3 Recommendations

Based on the findings of this study, the following recommendations were forwarded for improving instruction and for further research.

6.3.1 Recommendations for Instruction

- Curriculum developers should be aware of the most common identified categories of students' conceptions in each specific topic and should design the textbooks and curriculum based on these findings.
- Teachers of physics at all levels should emphasize the correct epistemological and ontological categorization of concepts during their teaching.
- Ministry of Education should design a means to build knowledge of in-service and pre-service physics teachers' in relation to contemporary theories of science learning.

6.3.2 Recommendations for Future Study

This thesis has covered only a selected area of physics concepts, the concepts of EPE and EMI. The selection of the topics was largely motivated by the conceptual difficulties of these concepts in the domain of electricity and magnetism. Thus, future research could perform a similar design of the study using different physics topics to have a more general idea of the categorization of different concepts. In addition, in order to build an inclusive theory on the categories of students' conceptions, cross-sectional and longitudinal studies on the same or similar concepts of physics are needed.

The conceptual change process studied in this thesis considered only epistemological and ontological perspectives of students' conceptions. However, conceptual change is a complex process that needs also affective perspective of students' conceptions (see Section 1.6). Hence, an inclusive multi-perspective conceptual change research that includes epistemological, ontological and affective perspective of students' conceptions should be undertaken in order to have more understanding of the theory.

As indicated in this study, conceptual change requires changes of naïve physics to expert physics, lateral alternative conceptions to correct lateral categories, ontological alternative conceptions to correct ontological categories and fragmented concepts to interrelated concepts. However, both the CCS and CPS strategies were limited in changing all the categories of alternative conceptions simultaneously. To address this limitation, a holistic confrontation (Chi, 2008, Gadgil et al., 2012) with concept maps may help to address all the categories of alternative conceptions. This means that students can examine a visual representation (e.g., concept maps) of their alternative conceptions of concepts in the categories and contrast them with concept maps of the correct categories of the concepts (expert maps), in terms of their predictions, explanations and elements of each category.

REFERECNCES

Albe, V., Venturini, P., & Lascours, J. (2001). Electromagnetic concepts in mathematical representation of physics. *Journal of Science Education and Technology, 10*(2), 197–203.

Abell, S. K., Eichinger, D.C. (1998). Examining the Epistemological and Ontological Underpinnings in Science Education: An Introduction. *Journal of Research in Science Teaching,* 35(2), 107-109.

Bao, L., & Redish, E. F. (2001). Concentration Analysis: A Quantitative Assessment of Student States. *Phys. Edu. Res., American Journal of Physics*. 69 (7), S45-53.

Bao, L., & Redish, E. F. (2006). Model analysis: Representing and assessing the dynamics of student learning. *Physical Review Special Topics-Physics Education Research*, 2(1), 010103.

Baser, M. (2006). Effects of Conceptual Change and Traditional Confirmatory Simulations on Pre-Service Teachers' Understanding of Direct Current Circuits. *Journal of Science Education and Technology*, 15(5), 367-381.

Baser, M & Durmus, S. (2010).The Effectiveness of Computer Supported Versus Real Laboratory Inquiry Learning Environments on the Understanding of Direct Current Electricity among Pre-Service Elementary School Teachers. *Eurasia Journal of Mathematics, Science & Technology Education,* 6(1), 47-61.

Baser, M., & Geban, O. (2007).Effect of instruction based on conceptual change activities on students' understandings of static electricity concepts. *Research in Science & Technological Education*, 25(2), 243- 267.

Bauchner, H., Boardman, B., & Palmer, D. (1996). Sixth and eighth graders and acquired immunodeficiency syndrome: The results of focus groups analysis. *Journal of Adolescent Health*, 19(4), 297-302.

Borges, A. T. (1999). Mental models of electricity. *International Journal of Science Education*, 21 (1), 95-117.

Borges, A. T. & Tecnico, C. (1998). Models of Magnetism. *International Journal of Science Education*, 20(3), 361-378.

Bilal, E., & Erol, M. (2009). Investigating students' conceptions of some electricity concepts. *Latin American Journal of Physics Education,* 3(2), 193-201.

Cakir, M. (2008). Constructivist Approaches to Learning in Science and Their Implications for Science Pedagogy: A Literature Review. *International Journal of Environmental & Science Education*, 3 (4) 193-206.

Carey, S. (1985). Conceptual change in childhood. Cambridge, MA: MIT press

Central Statistical Agency [Ethiopia] & ICF International, (2012). *Ethiopia Demographic and Health Survey 2011*. Addis Ababa, Ethiopia and Calverton, Maryland, USA: Central Statistical Agency and ICF International.

Chabay, R., & Sherwood, B. (2006). Restructuring the introductory Electricity & Magnetism course. *American Journal of Physics*, 74(4), 329-336.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction*, 15(1), 1–40.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences, 14*(2), 161-199.

Chi, M.T.H. (2008). Three types of conceptual change: Belief revision, mental model transformation and categorical shift. In S. Vosniadou (Ed), *Handbook of research on conceptual change*, 61-82. Hillsdale, NJ:Erlbaum.

Chi, M.T.H., & Roscoe, R.D. (2002). The processes and challenges of conceptual change. In M. Limon & L. Mason (Eds.), *Reconsidering Conceptual Change*: *Issues in Theory and Practice* (pp.3–27). Dordrecht: Kluwer Academic Publishers.

Chi, M .T. H,. & Slotta, J. D. (1993). The Ontological Coherence of Intuitive Physics. *Cognition and Instruction*, 10(2&3), 249-260.

Chi, M. T., De Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science*, *18*(3), 439-477.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science education. *Review of Educational Research*, 63 (1), 1-49.

Chinn, C. A., & Samarapungavan, A. (2009). 'Conceptual Change—Multiple Routes, Multiple Mechanisms: A Commentary on Ohlsson (2009)', *Educational Psychologist*. 44 (1), 48-57.

Clement, J. (1982). Students' Preconceptions in Introductory Mechanics, *American Journal of Physics,* 50, 66-71.

Clark, D. B. (2006). Longitudinal conceptual change in students' understanding of thermal equilibrium: An examination of the process of conceptual restructuring. *Cognition and Instruction, 24*(4), 467-563.

Clark, D. B., D'Angelo, C. M. & Schleigh, S. P. (2011). Comparison of Students' Knowledge Structure Coherence and Understanding of Force in the Philippines, Turkey, China, Mexico, and the United States, *Journal of the Learning Sciences*, 20(2), 207-261.

Coletta, V. P., Phillips, J. A., & Steinert, J. J. (2007). Interpreting force concept inventory scores: Normalized gain and SAT scores. *Physical review special topics-physics education research*, *3*(1), 010106.

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage Publications.

Demastes, S., Settlage, J., & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: cases of replication and comparison. *Journal of Research in Science Teaching, 32(5),* 535-550.

Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical review special Topics-Physics education research*, *2*(1), 010105.

Ding, L., & Beichner R. (2009). Approaches to data analysis of multiple-choice questions. *Physical Review Special Topics-Physics Education Research*, 5, 1-17.

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. *Cognitive Science*, 6(1), 37-75.

diSessa, A. A. (1993). Towards an epistemology of physics. *Cognition and Instruction*, 10, (2&3), 105–225.

diSessa, A.A., Gillespie, N., & Esterly, J. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science*, 28(6), 843-900.

Doyle, L., Brady, A. M., & Byrne, G. (2009). An overview of mixed methods research. *Journal of Research in Nursing* 14 (2) 175–185.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the ''Cognitive Conflict''strategy for conceptual change-Some implications, difficulties, and problems. *Science Education*, 74(5), 555-569.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*. 23(7), 5-12.

Duit, R. (2009). Students' and teachers' conceptions and science education. Kiel: *Institute for Science Education* (IPN) (Distributed electronically).

Duit, R., & Treagust, D. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science education*, 25(6), 671-688.

Dykstra, D.I., Boyle, C.F., & Monach, I. A., (1992). Studying conceptual change in learning physics. *Science Education,* 76 (6), 615-652.

Elby, A. (2010). Coherence vs. Fragmentation in student epistemologies: A reply to Smith & Wenk. *Electronic Journal of Science Education*, 14(1), 1-22.

Engelhadt, P. V., & Beichner, R. J. (2004). Students' understanding of current resistive electrical circuits. *American Journal of physics*, 72(1), 98-115.

Federal Democratic Government of Ethiopia (FDGE). (1994). *The education and training policy*. Addis Ababa: Ministry of Education, Ethiopia.

Federal Democratic Government of Ethiopia (FDGE). (2009, September 17). *Higher Education Proclamation No. 650/2009*. Federal Negarit Gazeta. Retrieved October 3, 2012 from http://www.unhcr.org/refworld/docid/4ba7a6152.html.

Finkelstein, N. (2005). Learning Physics in Context: A study of student learning about electricity and magnetism. *International Journal of Science Education*. 27(10), 1187-109.

Fosnot, C. T. (1993). Science education revisited: A defense of Piagetian constructivism. *Journal for research in Science Education*, 30(9), 1189-120.

Fosnot, C. T. (Ed). (1996). *Constructivism: theory, perspectives and practice*. New York and London: Teachers college, Columbia University,

Franklin, K.K., & Knight, W. H., (1995). Using focus groups to explore student opinion. Paper Presented at the 24th Annual Meeting of the Mid-south Educational Research Association, Bilolxi, MS. (ERIC Reproduction Document number ED388200)

Fredette, N., & Lochhead, J. (1980). Student conceptions of simple circuits. *Physics Teacher* 18(3), 194-198.

Gabel, D.L. (1998). The complexity of chemistry and implications for teaching. In B.J. Fraser, & K.G. Tobin (Eds) *International handbook of science education* (pp. 233–248). Dordrecht: Kluwer Academic Publishers.

Gadgil, S., Nokes, T. J., & Chi, M. T. H. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. *Learning and Instruction*, 22 (1), 47–61.

Galili, I. (1995). Mechanics Background Influences Students' Conceptions in Electromagnetism. *International Journal of Science Education*, 17 (3), 371-387.

Getenet, T. (2006). Causes of high attrition among physics PPC students. *The Ethiopian Journal of Education*, 26(1), 53-66.

Grayson, D.J. (1994). Concept Substitution: An instructional Strategy for Promoting Conceptual Change. *Research in Science Education*, 24, 102-111.

Greca, I., & Moreira, M. A. (1997). The kind of mental representation - models, propositions and images-used by college physics students regarding the concept of field. *International Journal of Science Education,* 19(6), 711–24.

Guruswamy, C., Somars, M. D. & Hussey, R. G. (1997). Students' understanding of the transfer of charge between conductors, *Physics Education,* 32, 91–96.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74.

Halloun, I., & Hestenes, D. (1985). Common sense concepts about motions. *American Journal of Physics*, 53(11), 1056-1064.

Hammer, D. (1996). Misconceptions or P-Primes: how may alternative perspectives of cognitive structure influence instructional perceptions and intentions? *The Journal of the Learning Sciences*, *5*(2), 97–127.

Hand, B., & Treagust, D.F. (1991). Student achievement and science curriculum development using a constructive framework. *School Science and Mathematics,* 91(4), 172-176.

Harland, T. (2003). Vygotsky's Zone of Proximal Development and Problem based Learning: Linking a theoretical concept with practice through action research. *Teaching in higher Education*, 8(2), 263-272.

Hardiman, P. T., Dufrersne, R.T., Robert,T., Mestre, J. P., (1989). The relation between problem categorization and problem solving among novices and experts. *Memory & cognition*, 17, 627-638.

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999). Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, 36(1), 55-87.

Hewson, M. G., & Hewson, P. W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching*. 20, 731-743.

Hewson, P. W., & Hewson, M. G. (1984). The role of conceptual conflict in conceptual change and the Design of Science Instruction. *Instructional Science*, 13, 1-13.

Hewson, P.W., & Thorley, R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education*, 11, 541–553.

Hewson, P.W. (1981). A conceptual change approach to learning science. *European Journal of Science Education*, 3, 383–396.

Howe A, Keogh-Brown, M., Miles, S., & Bachmann, M. (2007). Expert consensus on contamination in educational trials elicited by a Delphi exercise. *Medical Education*, 41(2), 196-204.

Huer, M. B. (2005). Using Concept Maps for Educational Based Implementation of Assistive Technology: A culturally inclusive model for supervision in special education**.** *Journal of Special Education Technology.* 20, 51-61.

Ioannides, C., & Vosniadou, S. (2002). The changing meaning of force. *Cognitive Science Quarterly*, 2(1), 5-61.

İpek, H., & Çalık, M. (2008). Combining Different Conceptual Change Methods within Four-Step Constructivist Teaching Model: A Sample Teaching of Series and Parallel Circuits. *International Journal of Environmental & Science Education.* 3(3), 143-153.

Jarrell, M.G., (2000). Focusing on Focus Group Use in Educational Research. Paper Presented at the Annual Meeting of the Mid-south Educational Research Association (28th, Bowling green, KY, November 15-17, 2000).

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion, *Computers & Education*, 36 (2), 183-204.

Johanson, R. B., & Onwuegbuzie, A. J, (2004). Mixed Methods Research: A Research Paradigm whose Time Has Come. *Educational Researcher,* 33(7), 14-26.

Keiny, S. (2008). 'Conceptual change' as both revolutionary and evolutionary process, *Teachers and Teaching: Theory and Practice*, 14 (1), 61-72.

Keogh-Brown, M. R., Bachmann, M.O., Shepstone, L., Hewitt, C., Howe, A., Ramsay, C.R., et al. (2007).Contamination in trials of educational interventions, *Health Technol Assess*, 11(43).

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions*. Chicago: Chicago University Press.

Lederman, N.G., & O'Malley, M. (1990).Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education,* 74(2), 225-239.

Lederman, L.C., (1990). Assessing educational effectiveness: The focus group interview as a technique for data collection. *Communication Education*, 39, 117-127.

Lee, G., & Byun, T. (2012). An explanation for the difficulty of leading conceptual change using a counterintuitive demonstration: The relationship between cognitive conflict and responses. *Research in Science Education*, 42 (5), 943-965.

Leppävirta, J. (2012). The Effect of Naïve Ideas on Students' Reasoning about Electricity and Magnetism. *Research in Science Education,* 42(4), 753-767.

Li, S. C. (2011). Cognitive Perturbation and Conceptual Change in Learning about Marine Ecology with Dynamic Modeling. *International Journal of Instructional Media*, 38 (4), 359-367.

Li, S. C., Law, N., & Lui, K. F. A., (2006). Cognitive perturbation through dynamic modeling: a pedagogical approach to conceptual change in science, *Journal of Computer Assisted Learning*. 22(6), 405-422.

Licht, P. & Thijs, G.D. (1990). Method to trace coherence and persistence of preconceptions. *International Journal of Science Education*, 12(4), 403-416.

Limon, M. (2001). On the Cognitive Conflict as an Instructional Strategy for Conceptual Changes: a Critical Appraisal. *Learning and Instruction*, 36 (4-5), 357-380.

Linder, C.J. (1993). A challenge to conceptual change. *Science Education,* 77, 293-300.

Long, C. (2005). Math concepts in teaching: procedural and conceptual knowledge. *Pythagoras*, 62 (7) 59-65.

Maloney, D.P. (1985). Charged Poles? *Physics Education*, 20(6), 310-316.

Maloney, D. P., O'Kuma, T. L., Hieggelke C. J., & Heuvelen, A.V., (2001). Surveying students' conceptual knowledge of electricity & magnetism. *American Journal of Physics*, S69 (7), 12-23.

Maloney, D.P. & Siegler R.S. (1993). Conceptual competition in physics learning. *International Journal of Science Education*, 15, 283–295.

Marx, J. D. (1998). Creation of a Diagnostic Exam for Introductory, Undergraduate Electricity and Magnetism (Doctoral dissertation, Rensselaer Polytechnic Institute). Retrieved December 5, 2010, from http://www.compadre.org/Repository/document/ServeFile.cfm?ID=3786&DocID=114

McCloskey, M. (1983). Intuitive physics, *Scientific American*, 248(4), 122-130.

McClure, J. R., Sonak, B., & Suen, H. K. (1999). Concept Map Assessment of Classroom Learning: Reliability, Validity, and Logistical Practicality. *Journal of Research in Science Teaching*, 36(4) 475–492.

McDermott, L.C., (2001). Oersted Medal Lecture 2001: Physics Education Research: The key to student Learning. *American Journal of Physics*, 69 (11) 1127- 1137.

McDermott, L. C., & Redish, E. F. (1999). Resource Letter: PER-1: Physics Education Research. *American Journal of Physics*, 67 (9), 755-767.

McDermott, L.C.. & Shaffer, P.S. (1992). Research as a guide for curriculum development: an example from introductory electricity, Part I: Investigation of student understanding. *American Journal of Physics*, 60(11), 994-1003.

Mestre, J., & Touger, J. (1989). Cognitive research – what's in it for physics teacher? *Physics Teacher,* 27 (6), 447-456.

Miller, K.J, Koury, K. A., Fitzgard, G. E.,Hollingsead, C., Mitchem, K., J., Tsai, H., &Park, M. (2009). Concept mapping as a research tool to evaluate conceptual change related to instruction methods. *Journal of the Teacher Education Division of the Council for Exceptional Children*. 32(4), 365-378.

Ministry of Education [MOE]. (2008). *Annual intake and enrollment growth and professional and program mix of Ethiopian public higher education: strategy and conversion plan, 2001-2005 E.C*. Ministry of Education, Addis Ababa, April 2008.

Ministry of Education [MOE]. (2009). Harmonized curriculum for BSc Degree program in Physics, Ethiopia. Addis Ababa.

Minstrell, J. (1982). Explaining 'at rest' condition of an object, *The Physics Teacher,* 20(1), 10-14.

Mistades, V. M. (2009). Concept Mapping in Introductory Physics. *Journal of Education and Human Development.* 3 (1), 1-6.

Morgan, D. L. (1996). Focus groups. *Annual Review of Sociology*, 22, 129–152.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners. *Science Education*, 86(4), 548-571.

Novak, J., & Gowin, B. (1984). *Learning How to Learn*. New York: Cambridge University Press.

Nussbaum, J., & Novice, S. (1982). Alternative Frameworks, Conceptual Conflict and Accommodation: Toward a Principled Teaching Strategy. *Instructional Science,* 11(3), 183-200.

Osborne, R. (1981). Children's ideas about electric current. *New Zealand Science Teacher*, 29, 12-19.

Osborne, R. (1983). Towards Modifying Children's Ideas about Electric Current. *Research in Science and Technological Education*, 1 (1), 73-83.

Özdemir, G., & Clark, D. B. (2007). An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(4), 351-361.

Pallant, J. (2007). *SPSS Survival Manual: A Step by Step Guide to Data Analysis using SPSS for Windows (*3rd ed.), Open University Press.

Panyan, M., Hillman, S., & Liggett, A. (1997). The role of focus groups in evaluating and revising teacher education programs. *Teacher Education and Special Education*, 20(1), 37-46.

Parker, A., & Tritter, J. (2006). Focus group method and methodology: current practice and recent debate, *International Journal of Research & Method in Education*, 29 (1), 23–37.

Pepper, R.E., Chasteen, S.V., Pollock, S.J. & Perkins, K. K., (2010). "Our best juniors still struggle with Gauss's law: Characterizing their difficulties", PERC Proceedings.

Perkins, D. (2006). Constructivism and troublesome knowledge. In Meyer J. H. F. & Land R (Eds.), *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge* (pp 33-47). NY: Routledge.

Pinarbasi, T, Canpolat, N., & Bayrakceken, S. (2006). An Investigation of Effectiveness of Conceptual change Text-oriented Instruction on Students' Understanding of solution concepts. *Research in Science Education*. 36, 313-335.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, 6, 167–199.

Planinic, M. (2006). Assessment of difficulties of some conceptual areas from Electricity & magnetism using the Conceptual survey of Electricity and magnetism. *American Journal of Physics*. 73(12), 1143-1148.

Planinic, M. (2007). Conceptual change requires insight and intervention. *Physics Education,* 42 (2), 222-223.

Planinic, M., Boone, W. J., Krsnik., R & Beilfuss, M. L. (2006). Exploring alternative conceptions from Newtonian dynamics and simple DC circuits: links between item difficulty and item confidence. *Journal of research in Science Teaching,* 43(2), 150-171.

Planinic, M., Krsnik ,R., Pecina, P., & Susac, A. (2005). Overview and Comparison of Basic Teaching Techniques that Promote Conceptual Change in Students. A paper presented at the First European Physics Education Conference. Bad Honnef, July 4-7, 2005, Germany.

Pollock, S. J. (2008, October). Comparing student learning with multiple research-based conceptual surveys: CSEM and BEMA. In *AIP Conference Proceedings* (Vol. 1064, p. 171).

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*. 66, 211–227.

Puchta, C., & Potter, J. (2004). *Focus group practice*, SAGE Publications, London

Punch, K. F. (2009). *Introduction to Research Methods in Education,* SAGE Publications.

Rabiee, F. (2004). Focus-group interview and data analysis, *Proceedings of the Nutrition Society*, 63, 655–660.

Ramadas, J., Barve, S., & Kumar, A. (1996). Alternative conceptions in Galilean relativity: inertial and non-inertial observers*, International Journal of Science Education*, 18(5), 615-629.

Rebello, N. S., Zollman, D. A., Allbaugh, A. R., Engelhardt, P. V., Gray, K. E., Hrepic, Z., et al. (2005). Dynamic Transfer: A Perspective from Physics Education Research. In J. P. Mestre (Ed.), Transfer of Learning from a Modern Multidisciplinary Perspective. Greenwich, CT: Information Age Publishing Inc.

Redish, E. F. (1994). Implications of cognitive studies for teaching physics. *American Journal of Physics*, *62*(9), 796-803.

Redish, E. F., & Smith, K. A. (2008). Looking beyond content: Skill development for enginers. *Journal of Engineering Education*, 97 (3), 295-307.

Ritchie, J., & Spencer, L. (1994). Qualitative data analysis for applied policy research. In Analyzing Qualitative Data, pp. 173–194 [A Bryman and RG Burgess, editors]. London: Routledge.

Rittle-Johnson, B. (2006). Promoting transfer: Effects of self-explanation and direct instruction. *Child Development*, 77(1), 1-15.

Rittle-Johnson, B., & Alibali, M. W. (1999). Conceptual and Procedural Knowledge of Mathematics: Does One Lead to the Other?. *Journal of Educational Psychology*, 91(1), 175-189.

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: An iterative process. *Journal of Educational Psychology*, 93, 346–362.

Rogoff, B. (1984). Introduction: thinking and learning in social context. In B. Rogoff, & J. Lave (Eds) *Everyday cognition: Its development in social context*. Cambridge, MA: Harvard University Press.

Rosen, Y., & Salomon, G. (2007). The differential learning achievements of constructivist technology-intensive learning environments as compared with traditional ones: A meta-analysis. *Journal of Educational Computing Research*, *36*(1), 1-14.

Rosenthal, A. S., & Henderson, C. (2006).Teaching about circuits at the introductory level: An emphasis on potential difference. *American Journal of Physics*, 74 (4), 324-328.

Roth, W. M., & Roychoudhury, A. (1994). Science discourse through collaborative concept mapping: new perspectives for the teacher. *International journal of science education*, *16*(4), 437-455.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and Issues in the Use of Concept Maps in Science Assessment. *Journal of Research in Science Teaching*, 33(6), 569-600.

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136-153.

Saglam, M., & Millar, R. (2004). Diagnostic test of students' ideas in electromagnetism. Retrieved October 29, 2010, from http://www.york.ac.uk/depts/educ/research/ResearchPaperSeries/index.htm

Saglam, M., & Millar, R. (2006). Upper High School Students' Understanding of Electromagnetism. *International Journal of Science Education*. 28 (5), 543-566.

Scaife, T. M., & Heckler, A. F. (2010). Student understanding of the direction of the magnetic force on a charged particle. *American Journal of Physics*, 78 (8), S69-S76.

Semela, T. (2010).Who is joining physics and why? Factors influencing the choice of physics among Ethiopian university students. *International Journal of Environmental & Science Education,* 5(3), 319-340.

Serway,R, A., & Jewwett J. W. (2002). *Principles of physics: A calculus base text*. Australia: Thomson learning.

Sewell, A. (2002).Constructivism and Student Misconceptions: Why every teacher needs to know about them. *Australian Science Teachers Journal*, 48 (4), 24-28.

Shaka, F. L., & Bitner, B. L. (1996). Construction and validation of a rubric for scoring concept maps. In P. A. Rubba, P. F. Keig, & J. A. Rye (Eds.), *Proceedings of the 1996 Annual International Conference of the Association for the Education of Teachers in Science*, (pp650-669).

Shipstone, D. M. (1984). A Study of Children's Understanding of Electricity in Simple D.C. Circuits. *European Journal of Science Education*, 6, 185-198.

Soto-Lombana, C., Otero, J., & Sanjosé,V. (2005). A review of conceptual change research in science education. *Journal of Science Education,* 6, (1), 5-8.

Stavy, R, (1998). Special Issue: Conceptual Development in Science Education. *International Journal of Science Education.* 20(10), 1151-1154.

Streveler, R. A., Litzinger, T. A., Miller, R.L. & Steif, P. S. (2008). Learning Conceptual Knowledge in the Engineering Sciences: Overview and Future Research Directions. *Journal of Engineering Education*, 97(3), 279-294.

Stocklmayer, S. (2010). Teaching Direct Current Theory Using a Field Model. *International Journal of Science Education*, 32(13) 1802-1828.

Stoddart, T., Abrams R., Gasper, E. & Canaday, D. (2000). Concept maps as assessment in science inquiry learning - a report of methodology. *International of Journal Science Education* .22 (12), 1221- 1246.

Stofflett, R.T., & Stoddart, T. (1994). The ability to understand and use conceptual change pedagogy as a function of prior content learning experience. *Journal of Research in Science Teaching, 31 (1),* 31-51.

Tao, P.K., & Gunstone, R.F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching,* 36(7), 859-882.

Thagard, P. (1990). Concepts and conceptual change. *Syntheses*, *82*, 255-274.

Thong, W. M., & Gunstone, R. (2008). Some Student Conceptions of Electromagnetic Induction. *Research in Science Education*, 38(1), 31-44.

Tennyson, R. D., & Cocchiarella, M. J. (1986). An empirically based instructional design theory for teaching concepts. *Review of Educational Research*, 56, 40-71.

Treagust, D., & Duit, R. (2008). Conceptual Change: A Discussion of Theoretical, Methodological and Practical Challenges for Science Education. *Cultural Studies of Science Education*, 3(2), 297-328.

Urban-Woldron, H. (2009). Interactive Simulations for the Effective Learning of Physics. *Journal of Computers in Mathematics and Science Teaching*, 28(2), 163-176.

Van Zele, E., Lenaerts, J., & Wieme, W. (2004). Improving the usefulness of concept maps as a research tool for science education. *International Journal of Science Education*, 26(9), 1043-1064.

Venville,G. J., Louisell, R. D., & Wilhelm, J. A. (2012). Young Children's Knowledge about the Moon: A Complex Dynamic System. *Research in Science Education,* 42(4), 729-752.

Von Glasersfeld, E., & Steffe, L, P. (1991). Conceptual models in Educational research and practice. *Journal of Educational Thought*, 25(2), 91-103.

Vosniadou, S. (1999). Conceptual change research: State of the art and future directions. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives in conceptual change* (pp. 3–13). New York: Pergamon Press.

Vosniadou, S. (2007). Conceptual Change and Education, *Human Development*. 50, 47-54.

Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. *Review of Educational Research*, 57(1), 51–67.

Vosniadou, S., & Brewer, W.F. (1992). Mental models of the earth. A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535-585.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, *18*(1), 123-183.

Vosniadou, S., & Ioannides, C. (1998). From Conceptual development to Science Education: a psychological Point of View. *International Journal of science Education*. 20 (10), 1213-1230.

Vygotsky, L.S. (1978). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.) Mind in society. Cambridge, MA: Harvard University Press.

Wellman, H. M.,&Gelman, S. (1992). Cognitive development: Foundational theories of core domains. *Annual Review of Psychology, 43*, 337–375.

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008a). PhET: Simulations that enhance learning. *Science*, 322(5902), 682-683.

Wieman, C. E., Perkins, K. K. & Adams, W. K. (2008b). Oersted Medal Lecture 2007: Interactive simulations for teaching physics: What works, what doesn't, and why. *American Journal of Physics*, 76 (4&5), 393-399.

Wilson, V. (1997). Focus Groups: a useful qualitative method for educational research. British *Educational Research Journal*, 23: (2), 209-224.

Wiser, M., & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction,* 11, 33-353

Wiser, M., & Carey, S. (1983). When heat and temperature were one. In D. Gentner & A. Stevens (Eds.), *Mental models* (pp. 267-298), Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Zacharia, Z., & Anderson, O. R. (2003).The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics*, 71 (6), 618-629.

Zajchowski, R., & Martin, J. (1993). Differences in the problem solving of stronger and weaker novices in physics: Knowledge, strategies or knowledge structure? *Journal of Research in Science Teaching*, 30 (5), 459-470.

Zavala, G., & Alarcon, H. (2008, October). Evaluation of Instruction Using the Conceptual Survey of Electricity and Magnetism in Mexico. In *AIP Conference Proceedings* (Vol. 1064, p. 231).

Zohar, A., & Aharon-Kravetsky, S. (2005). Exploring the effects of cognitive conflict and direct teaching for students of different academic levels. *Journal of Research in Science Teaching*, 42(7), 829-855.

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry. *Journal of Research in Science Teaching,* 27(10), 1053- 1065.

Appendix A: Modified Diagnostic Exam of Electricity and Magnetism

Diagnostics Test of Electric Potential, Energy and Electromagnetic Induction (Modified DEEM)

In any question referring to current, conventional current will be used (where conventional current is the flow of positive charges). In addition, all effects due to the earth's magnetic field will be so small that they will be ignored. Note that the term "particle" is meant to be an object without size or structure.

FOR QUESTIONS 1-2

A positive charge is placed at rest at the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the region)

1) When the positive charge is released from rest in the uniform electric field, what will its subsequent motion be?
   A) It will move at a constant speed.
   B) It will move at a constant velocity.
   C) It will move at a constant acceleration.
   D) It will move with a linearly changing acceleration.
   E) It will remain at rest in its initial position

2) What happens to the electric potential energy of the positive charge, after the charge is released from rest in the uniform electric field?
   A) It will remain constant because the electric field is uniform.
   B) It will remain constant because the charge remains at rest.
   C) It will increase because the charge will move in the direction of the electric field.
   D) It will decrease because the charge will move in the opposite direction of the electric field.
   E) It will decrease because the charge will move in the direction of the electric field.

For questions 3-11, a point (•) is representing location in space. The minus sign (**−**) represents particles with a net negative charge and positive sign (**+**) represents a net positive charge. The magnitudes of the net charges are all equal. Fields presented in each figure are only due to charges in the figure.

Items 3-10 ask questions about the values of quantities, not their magnitudes. For example, the value of 1 is greater than the value of -5.

Fig. 1

3) What is the value of the electrostatic potential at the point in the figure 1?
   A) The exact value cannot be determined, but it must be less than 0.
   B) The value is zero.
   C) The exact value cannot be determined, but it must be greater than 0.
   D) The electrostatic potential is not defined at the point.
   E) There is not enough information to determine anything about the value.

4) Relative to the value of electrostatic potential at the point in the figure 1 for question 3, what would happen to the value of the electrostatic potential at the point, if the point moves farther to the right?
   A) The value of the electrostatic potential at the point would be greater.
   B) The value of the electrostatic potential at the point would be less.
   C) The value of the electrostatic potential at the point would not change.
   D) The electrostatic potential is not defined at the point.
   E) There isn't enough information.

5) What is the direction of the electrostatic potential at the point in the figure 1?
   A) →
   B) ←
   C) Since the electrostatic potential at the point is zero, it cannot have a direction.
   D) Electrostatic potential does not have a direction.
   E) The electrostatic potential is undefined at the point.

6) What is the value of the electrostatic potential at the point in the figure 2?

Fig. 2

   A) The exact value cannot be determined, but it must be less than 0.
   B) The value is zero.
   C) The exact value cannot be determined, but it must be greater than 0.
   D) The electrostatic potential is not defined at the point.
   E) There is not enough information to determine anything about the value.

7) Relative to the value of electrostatic potential at the point in the fig. 2 for question 6, what would happen to the value of the electrostatic potential at the point, if the point were moved farther to the right?
   A) The value of the electrostatic potential at the point would be greater.
   B) The value of the electrostatic potential at the point would be less.
   C) The value of the electrostatic potential at the point would not change.
   D) The electrostatic potential is not defined at the point.
   E) There isn't enough information.

8) What can be said about the value of the electrostatic potential energy for the system of charged particles in the figure 3?

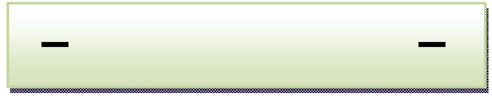


Fig. 3

A) The exact value cannot be determined, but it must be less than 0.
B) The value is zero.
C) The exact value cannot be determined, but it must be greater than 0.
D) The electrostatic potential energy is only defined at a specific location in space.
E) There is not enough information to determine anything about the value.

9) Relative to the electrostatic potential energy of the system in figure 3 for question number 8, what would happen to the value of the electrostatic potential energy if the two charged particles were moved to a new position farther apart?

A) The value of the electrostatic potential energy would be greater.
B) The value of the electrostatic potential energy would be less.
C) The value of the electrostatic potential energy would not change.
D) The electrostatic potential energy is only defined at a specific location in space.
E) There is not enough information.

10) What can be said about the value of the electrostatic potential energy for the system of charged particles in the figure 4?

Fig. 4

A) The exact value cannot be determined, but it must be less than 0.
B) The value is zero.
C) The exact value cannot be determined, but it must be greater than 0.
D) The electrostatic potential energy is only defined at a specific location in space.
E) There is not enough information to determine anything about the value.

11) Relative to the electrostatic potential energy of the system in figure 4, what would happen to the value of the electrostatic potential energy if the two charged particles were moved to a new position farther apart?

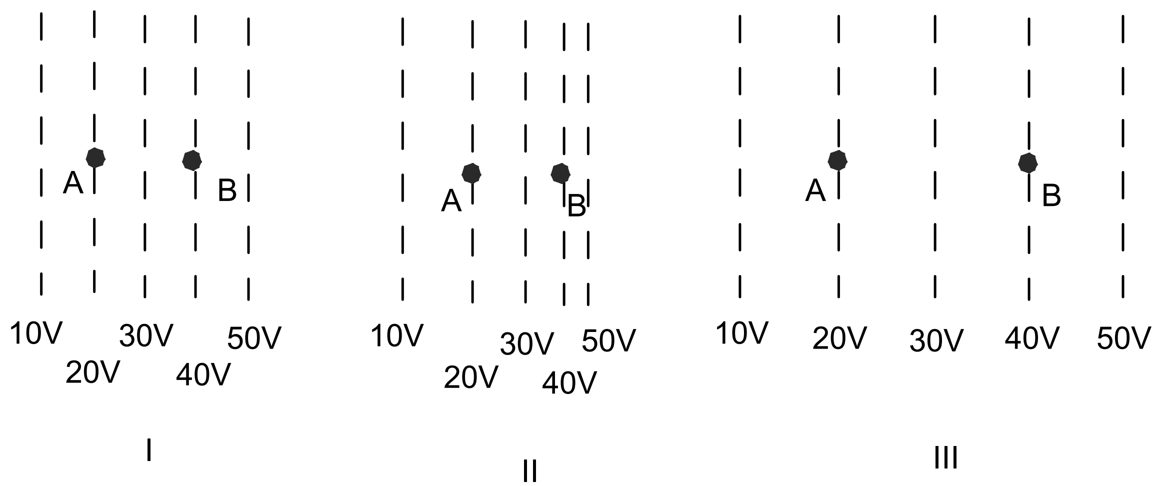
A) The value of the electrostatic potential energy would be greater.
B) The value of the electrostatic potential energy would be less.
C) The value of the electrostatic potential energy would not change.
D) The electrostatic potential energy is only defined at a specific location in space.
E) There is not enough information.

12) An electron is placed at a position on the x-axis where the electric potential is + 10 V. Which idea below best describes the future motion of the electron?

A) The electron will move left (-x) since it is negatively charged.
B) The electron will move right (+x) since it is negatively charged.
C) The electron will move left (-x) since the potential is positive.
D) The electron will move right (+x) since the potential is positive.
E) The motion cannot be predicted with the information given.

FOR QUESTIONS 13-14

In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.



13) How does the amount of work needed to move this charge compare for these three cases?
A) Most work required in I.
B) Most work required in II.
C) Most work required in III.
D) I and II require the same amount of work but less than III.
E) All three would require the same amount of work.

14) How does the magnitude of the electric field at B compare for these three cases?
A) I > III > II
B) I > II > III
C) III > I > II
D) II > I > III
E) I = II = III

Questions 15 and 16 refer to figure 5. A thin, circular, conducting loop, in the plane of the page, is immersed in a uniform, magnetic field pointed perpendicularly out of the page.

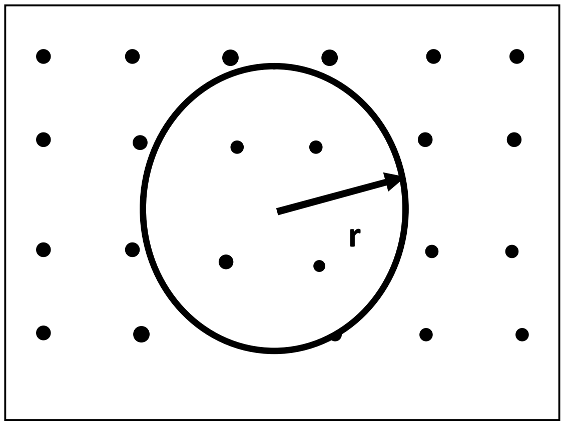


Fig.5

15) If the magnitude of the magnetic field does not change, but the radius, r, of the loop decreases, then which answer below describes something that happens to the loop?
    A) Nothing.
    B) A clockwise current is produced in the loop.
    C) A counterclockwise current is established in the loop.
    D) The loop will rotate clockwise in the plane of the page.
    E) The loop will rotate counterclockwise in the plane of the page.
16) If the radius, r, of the loop does not change, but the magnitude of the magnetic field decreases, then which one below describes something that happens to the loop?
    A) Nothing.
    B) A clockwise current is produced in the loop.
    C) A counterclockwise current is established in the loop.
    D) The loop will rotate clockwise in the plane of the page.
    E) The loop will rotate counterclockwise in the plane of the page.

For questions 17 and 18 consider only the space contained within the finite area of figure 6. The magnitudes of the net charges are all equal.

Fig. 6

17) For the charges in the figure 6, where is the electrostatic potential zero?
    A) Somewhere to the left of the two particles.
    B) Exactly halfway between the two particles.
    C) Somewhere to the right of the two particles.
    D) Nowhere in the figure.
    E) More information is needed.

18) For charges in the figure 7, where is the electrostatic potential zero?

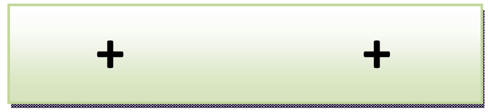
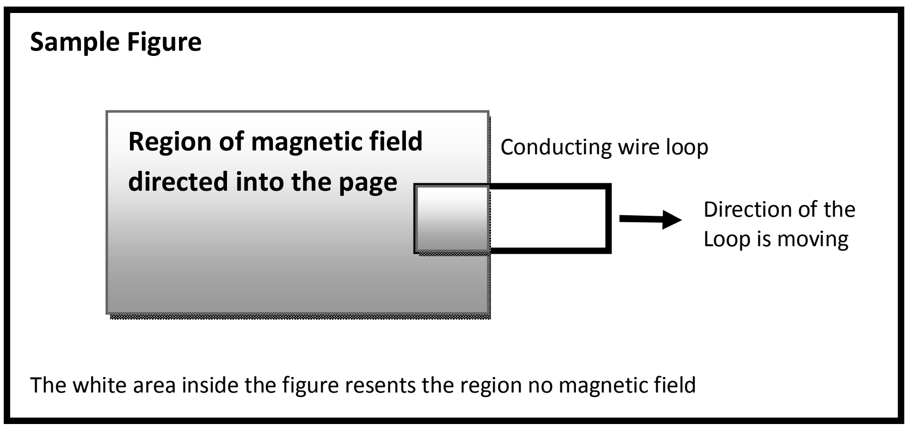


Fig. 7

A) Somewhere to the left of the two particles.
B) Exactly halfway between the two particles.
C) Somewhere to the right of the two particles.
D) Nowhere in the figure.
E) More information is needed.

For questions 19-22 the thick, black rectangles represent conducting, wire loops. Assume the wire to be of negligible thickness. The gray areas represent regions of magnetic field directed perpendicularly into the page. The black arrows represent the direction of motion of the wire loops. No arrow indicates that the loop is not moving. Look at the sample figure below for an example.



19) Choose an answer that describes something that happens to the wire loop as it moves as shown in the figure 8 to the right. The magnetic field in the gray region is **uniform**.

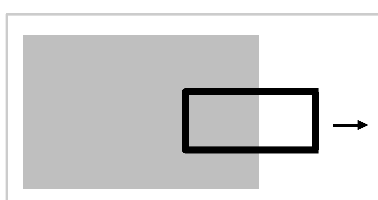


Fig. 8

A) There is not enough information given to answer the question.
B) A counterclockwise current is produced.
C) A clockwise current is produced.
D) No current is produced.
E) The wire loop tends to rotate

20) Choose an answer that describes something that happens to the wire loop as it moves as shown in the figure 9 to the right. The magnetic field in the gray region is **non-uniform**.

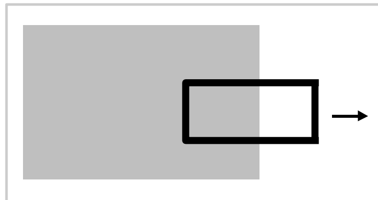


Fig. 9

A) There is not enough information given to answer the question.
B) A counterclockwise current is produced.
C) A clockwise current is produced.
D) No current is produced.
E) The wire loop tends to rotate

21) Choose an answer that describes something that happens to the stationary wire loop in the figure 10 to the right. The magnetic field in the gray region is **uniform**.

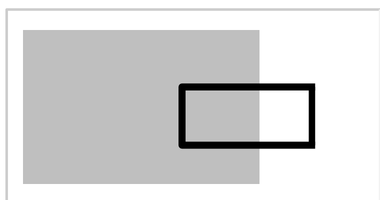


Fig. 10

A) There is no enough information given to answer the question.
B) A counterclockwise current is produced.
C) A clockwise current is produced.
D) No current is produced.
E) The wire loop tends to rotate.

22) Choose an answer that describes something that happens to the wire loop as it moves as shown in the figure 11 to the right? The magnetic field in the gray region is **uniform**.

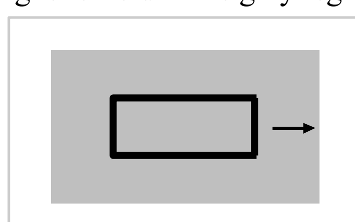


Fig. 11

A) There is not enough information given to answer the question.
B) A counterclockwise current is produced.
C) A clockwise current is produced.
D) No current is produced.
E) The wire loop tends to rotate

23) An observer watches a thin, circular, conducting, wire loop enter a region of a non-uniform magnetic field (see Figure A- TOP VIEW). The thick, dotted, black arrow in both views indicates the direction the loop is moving. Looking at the loop as it enters the non-uniform magnetic field directed into the page (see Figure A- SIDE VIEW), which answer below describes something, if anything, that happens to the loop as viewed by the observer?

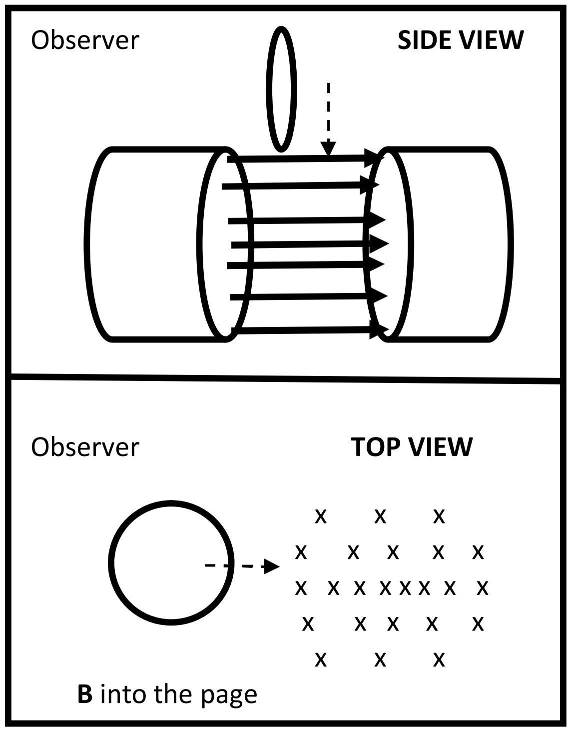


Figure- A

A) A counterclockwise current is created in the wire loop.
B) A clockwise current is created in the wire loop.
C) Nothing could happen to the wire loop as it enters any magnetic field.
D) Nothing happens because the field is non- uniform.
E) No answer can be given based on the information given.

24) An observer watches a region of a non-uniform magnetic field pass across a thin, circular, conducting, wire loop (see Figure B- TOP VIEW). The thick, dotted, black arrow in both views indicates the direction the magnetic field is moving. Looking at the loop, as the non-uniform magnetic field begins to passes across it (see Figure B- SIDE VIEW), which answer below describes something, if anything, that happens to the loop as viewed by the observer?

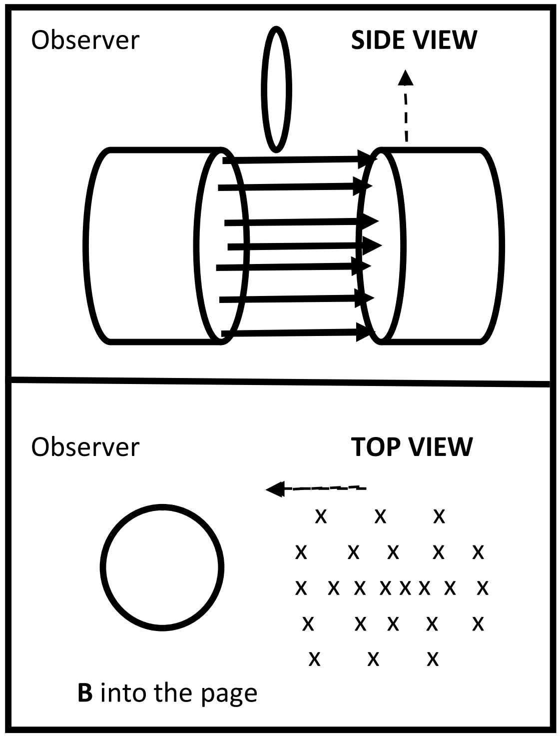
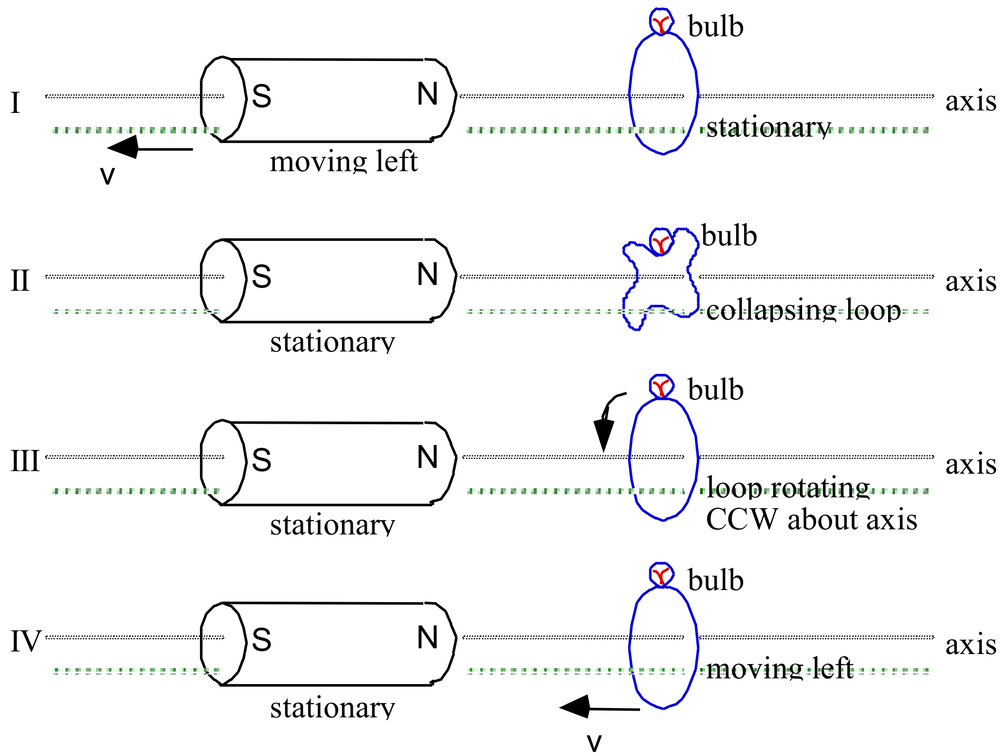


Figure- B

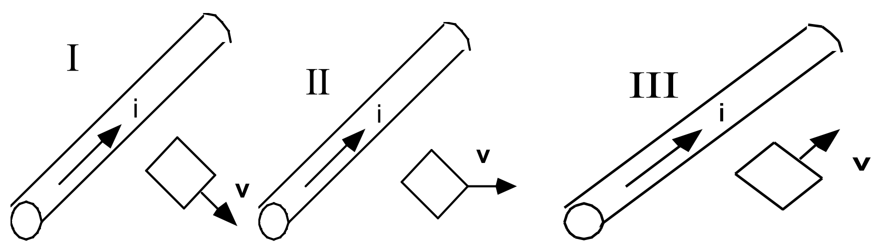
A) A counterclockwise current is created in the wire loop.
B) A clockwise current is created in the wire loop.
C) Nothing could happen to the wire loop as it enters any magnetic field.
D) Nothing happens because the field is non- uniform.
E) No answer can be given based on the information given.

The four separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. These figures are to be used in the following question. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise.

25) In which of the below figures will the light bulb be glowing?
A) I,III,IV
B) I, IV
C) I, II, IV
D) IV
E) None of these

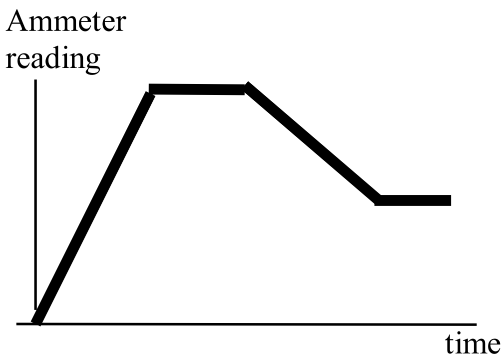


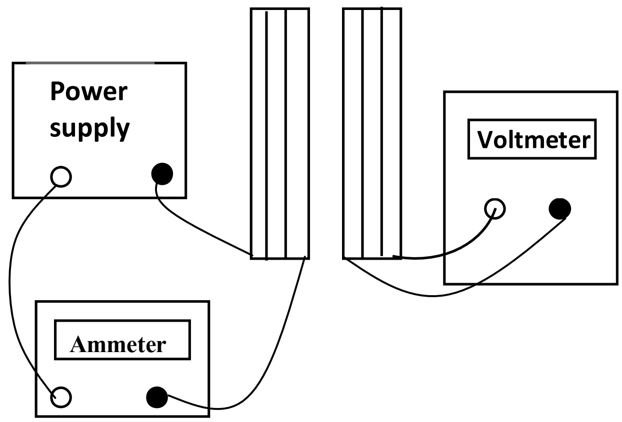
26) A very long straight wire carries a large steady current i. Rectangular metal loops, in the same plane as the wire, move with velocity **v** in the directions shown. Which loop will have an induced current?



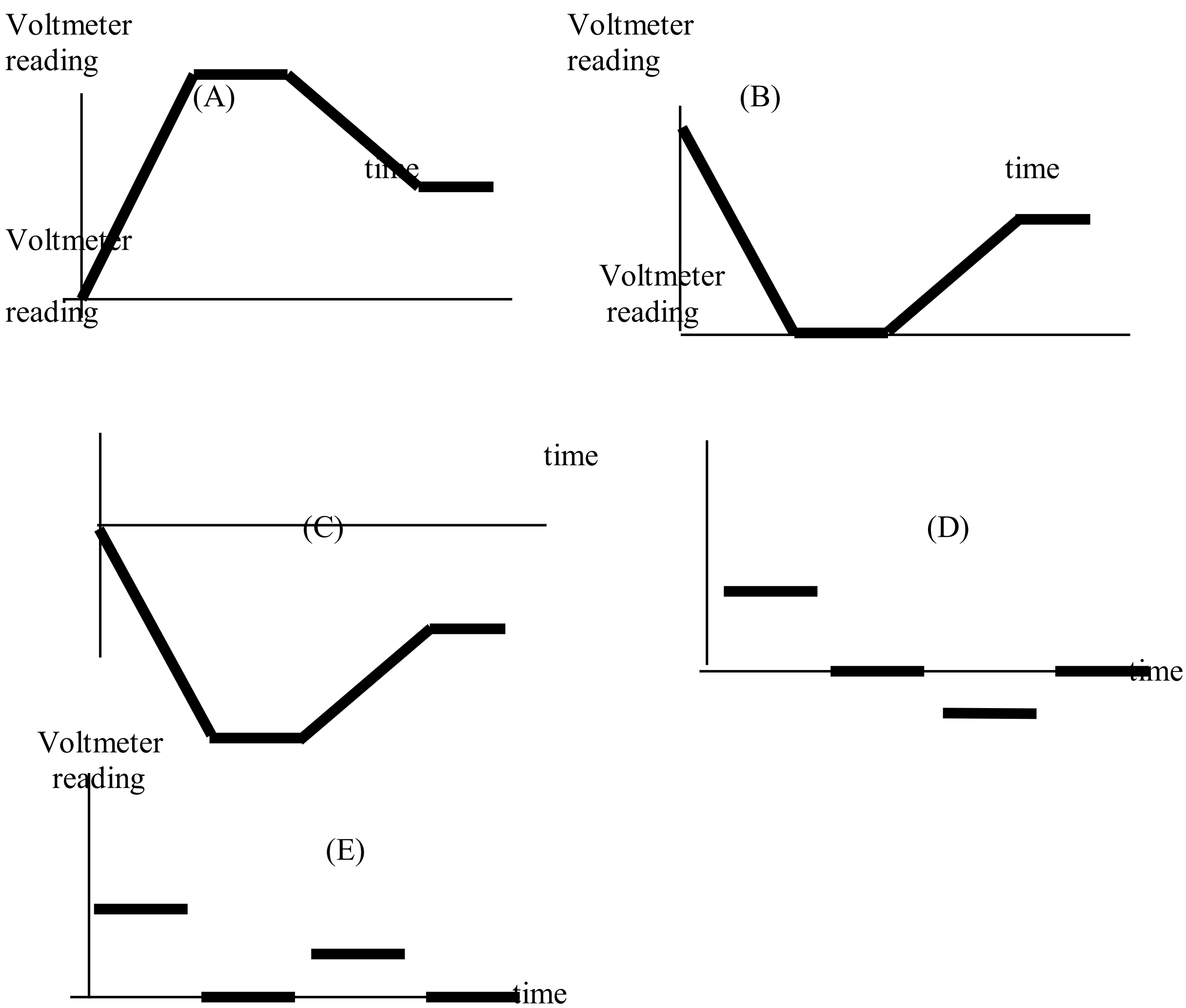
A) only I and II
B) only I and III
C) only II and III
D) all of the above
E) none of the above

27) A variable power supply is connected to a coil and an ammeter, and the time dependence of the ammeter reading is shown. A nearby coil is connected to a voltmeter.

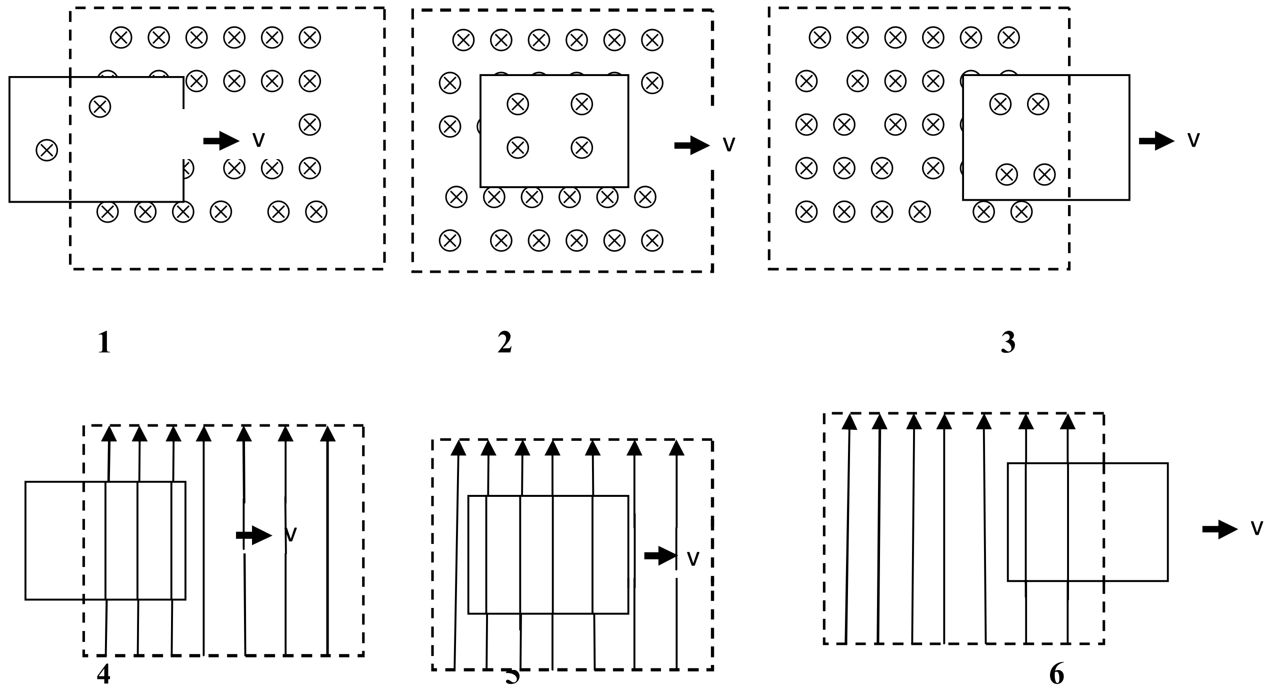




Which of the following graphs correctly shows the time dependence of the voltmeter reading?



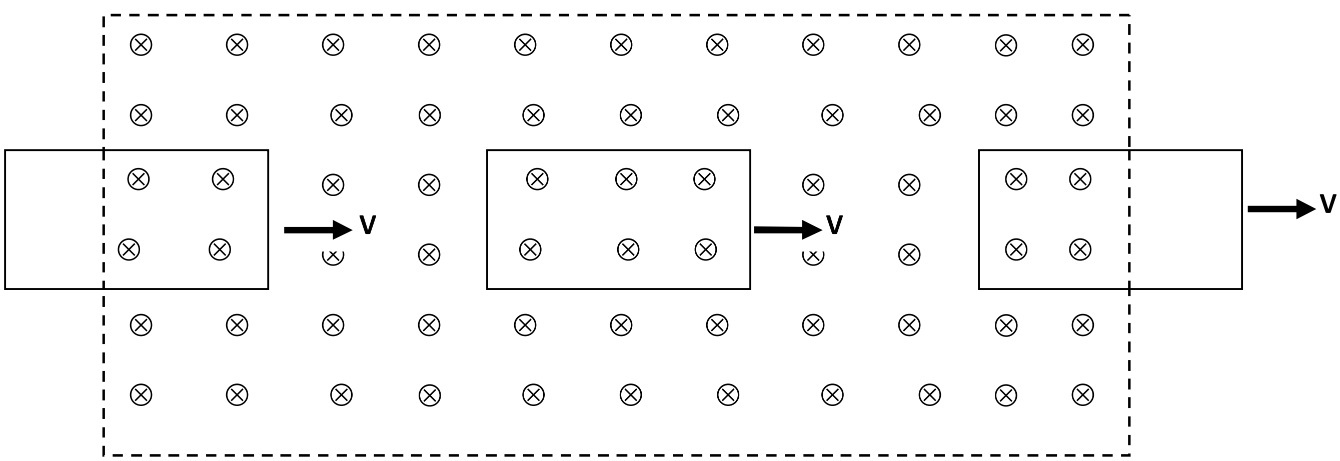
The diagram below shows six identical flat coils moving with the same constant speed v. The strength of the magnetic field is the same in each case. The field is confined to the region indicated by the dashed lines.



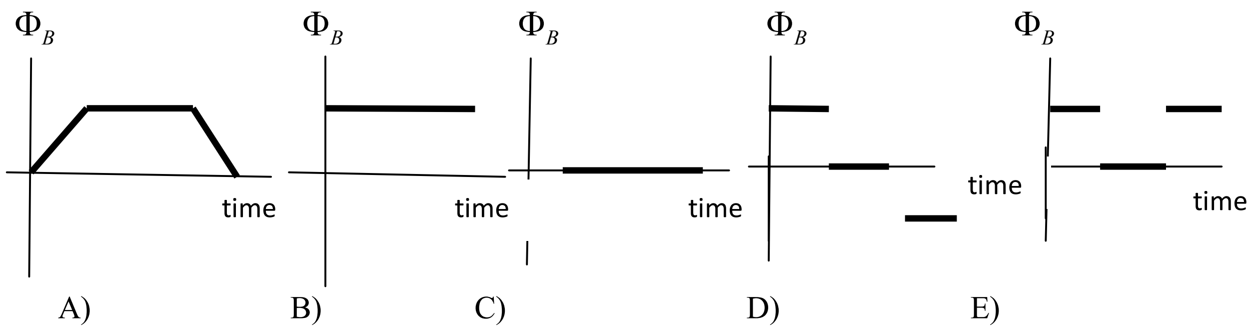
28) In which of the coil in the above diagram there is any induced emf ?

A) In all 1, 2 & 3 B) In all 4,5 & 6 C) In all 1, 3,4 & 6 D) In both 1&3 E) In both 2&5

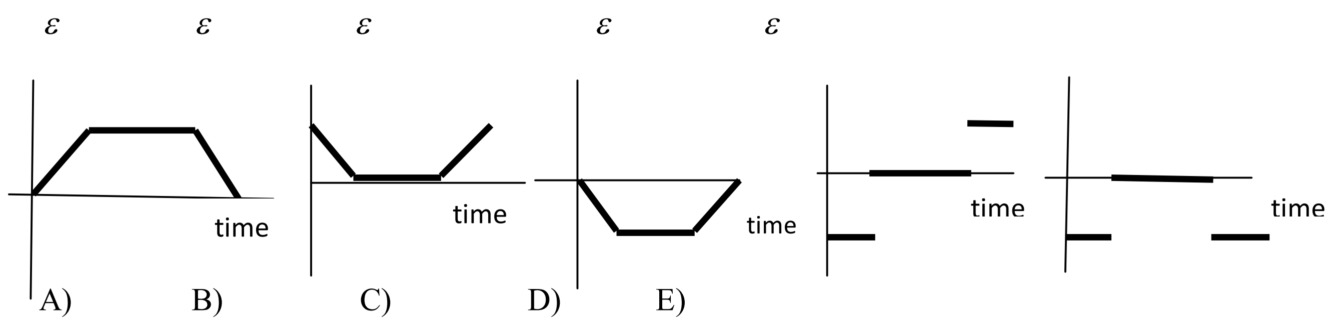
The diagram below shows a flat coil moving at constant speed in a uniform magnetic field. The magnetic field is confined to the region indicated by the dashed lines.



29) Which of the graphs below shows how the magnetic flux Φ_B through the coil changes from the moment it enters the field until the moment it leaves the field?



30) Which of the graphs below shows how the induced emf ε in the coil changes from the moment it enters the field until the moment it leaves the field?



Appendix B: Focus Groups Formation

Table B1: Descriptive Statistics of CSEM score

	N	Minimum	Maximum	Mean	Median	Std. Deviation
CSEM score	45	9.4	40.6	20.8	21.9	6.4
Valid N (list wise)	45					

Table B2: Initial four Focus groups (n=45)

CP1		CP2		CC1		CC2	
CODE	Score	CODE	Score	CODE	Score	CODE	Score
CP04	28.1	CP15	21.9	CC17	40.6	CC08	18.8
CP11	28.1	CP22	21.9	CC23	31.3	CC19	18.8
CP13	28.1	CP02	18.8	CC07	28.1	CC21	18.8
CP16	28.1	CP06	18.8	CC18	28.1	CC22	18.8
CP05	25.0	CP09	18.8	CC06	25.0	CC12	15.6
CP10	25.0	CP14	18.8	CC10	25.0	CC14	15.6
CP12	25.0	CP20	18.8	CC02	21.9	CC03	12.5
CP18	25.0	CP19	15.6	CC09	21.9	CC04	12.5
CP23	25.0	CP21	15.6	CC11	21.9	CC05	12.5
CP07	21.9	CP01	12.5	CC13	21.9	CC15	12.5
CP08	21.9	CP17	12.5	CC20	21.9	CC16	9.4
		CP03	9.4				

Table B3: CSEM mean scores of the four focus groups (n=45)

Tukey HSD[a,b]

Focus group	N	Subset for alpha = .05	
		1	2
CC2	12	16.1583	
CP2	11	17.3545	
CP1	11		24.1455
CC1	11		26.1455
Sig.		.935	.758

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.234.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guranted

Table B4: Descriptive statistics of students participated in the focus groups discussion (n=35)

Group	Mean	Std. Deviation	N	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
CC1	26.7444	6.25822	9	1.435	23.818	29.671
CC2	16.0375	3.53510	8	1.522	12.933	19.142
CP1	25.3444	2.42338	9	1.435	22.418	28.271
CP2	15.9889	3.97978	9	1.435	13.062	18.916
Total	21.1714	6.56042	35			

Table B5: Multiple Comparisons of means of focus groups (n=45)

Dependent Variable: CSEM score
Tukey HSD

(I)Focus group	(J Focus group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interva	
					Lower Bound	Upper Bour
CC1	CC2	9.98712*	2.00642	.000	4.6147	15.359
	CP1	2.00000	2.04958	.764	-3.4880	7.488
	CP2	8.79091*	2.04958	.001	3.3029	14.278
CC2	CC1	-9.98712*	2.00642	.000	-15.3596	-4.614
	CP1	-7.98712*	2.00642	.002	-13.3596	-2.614
	CP2	-1.19621	2.00642	.933	-6.5686	4.176
CP1	CC1	-2.00000	2.04958	.764	-7.4880	3.488
	CC2	7.98712*	2.00642	.002	2.6147	13.359
	CP2	6.79091*	2.04958	.010	1.3029	12.278
CP2	CC1	-8.79091*	2.04958	.001	-14.2789	-3.302
	CC2	1.19621	2.00642	.933	-4.1762	6.568
	CP1	-6.79091*	2.04958	.010	-12.2789	-1.302

*. The mean difference is significant at the .05 level.

Table B6: Multiple Comparisons of focus groups' means scores (n=35)

Dependent Variable: CSEM score
Tukey HSD

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
CC1	CC2	10.7069*	2.09180	.000	5.0297	16.3842
	CP1	1.4000	2.02934	.900	-4.1078	6.9078
	CP2	10.7556*	2.02934	.000	5.2478	16.2633
CC2	CC1	-10.7069*	2.09180	.000	-16.3842	-5.0297
	CP1	-9.3069*	2.09180	.001	-14.9842	-3.6297
	CP2	.0486	2.09180	1.000	-5.6287	5.7259
CP1	CC1	-1.4000	2.02934	.900	-6.9078	4.1078
	CC2	9.3069*	2.09180	.001	3.6297	14.9842
	CP2	9.3556*	2.02934	.000	3.8478	14.8633
CP2	CC1	-10.7556*	2.02934	.000	-16.2633	-5.2478
	CC2	-.0486	2.09180	1.000	-5.7259	5.6287
	CP1	-9.3556*	2.02934	.000	-14.8633	-3.8478

Based on observed means.

*. The mean difference is significant at the .05 level.

Table B7: Focus groups after withdrawal of some members (n=35)

Tukey HSD[a,b,c]

Group	N	Subset 1	Subset 2
CP2	9	15.9889	
CC2	8	16.0375	
CP1	9		25.3444
CC1	9		26.7444
Sig.		1.000	.904

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square (Error) = 18.532.

a. Uses Harmonic Mean Sample Size = 8.727.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

Appendix C: Concept Maps Question

Draw concept maps of electricity and magnetism concepts listed below. You are free to include additional related concepts to the list and incorporate them to your concept maps.

List of Concepts in Electricity and Magnetism

1. Electric potential
2. Potential difference
3. Electric potential energy
4. Kinetic energy
5. Equipotential lines
6. Electric charge
7. Electric field
8. Magnetic flux
9. Faraday's law
10. Magnetic field lines
11. Magnetic field
12. Electromagnetic induction
13. Induced electromotive force
14. Induced current

Appendix D: Student Research Consent Form

(To be completed by student participant aged 18 years and above)

1. **Research Topic**: Conceptual Change through Cognitive Perturbation using Simulations in Electricity and Magnetism: a Case Study in Ambo University, Ethiopia
2. **Purpose of the Research:** The purpose of this study is to investigate students' conceptual change in selected conceptual areas of undergraduate electricity & magnetism by supporting their learning with Cognitive Perturbation strategy through interactive physics simulations.
3. **Researcher's Details**:- **Name**: Bekele Gashe Dega (DEGA B G)
   Address: Ambo University, P.O.Box 19, AMBO, Ethiopia
   Telephone: 251911894519 (mobile), 251112365296 (Home)
4. **Research Site**: Ambo University, Oromia Regional State, Ethiopia

Participant's Name: ____________________________ Position___________________

Address: __________________________________ Telephone: _________________

5. **Participant Rights and Assurances**

I have received a copy of the Consent Letter for the aforementioned research study. Having read the application I am familiar with the purpose, methods, scope, and intent of the research study.
Please check one of the following:

I am willing ______ I am not willing_______ to participate in the research study. I understand that during the course of this research my responses will be kept strictly confidential and that none of the data released in this study will identify me by name or any other identifiable data, descriptions, or characterizations. Furthermore, I understand that I may discontinue my participation in this study at any time or refuse to respond to any questions to which I choose not to respond. I am a voluntary participant and have no liability or responsibility for the implementation, methodology, claims, substance, or outcomes resulting in any adverse consequences or disparate treatment due to that decision. I fully understand that this research is being conducted for constructive educational purposes and that my signature gives my consent to voluntarily participate in this study.

Participant's Signature ____________________________________

Date____

Appendix E: Ethical Clearance

UNISA | university of south africa

2 June, 2011

Mr. Bekele Gashe D.

Ethiopia

Dear Mr, Bekele,

REQUEST FOR ETHICAL CLEARANCE: Diognosis of Students' Alternative Conceptions and Conceptual Change through Cognitive Perturbation and simulation in Undergraduate Electricity & Magnetism in Ethiopia

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.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150

Appendix F: Focus Groups Discussion Questions

I. Electric Potential and Energy (EPE)

1. What is electric potential?
2. What is electric potential energy?
3. What relationships between electric potential and electric field could exist?
4. How would electric potential and potential energy be related?

II. Electromagnetic Induction (EMI)

1. What is electromagnetic induction?
2. What is magnetic flux?
3. How could an induced current/induced voltage be produced in a coil?
4. How could current in one coil be related to the voltage in another nearby coil?
5. How would motion of a coil or a source of magnetic field motion or variation of magnetic field be related to an induced current?

Appendix G: Scoring Rubric for Concept Maps

CM elements	4	3	2	1	0
Propositions	Complete, meaningful and valid.	Most are meaningful and valid.	Some are meaningful and valid.	Incomplete, few are meaningful.	Missing or not meaningful.
Hierarchy	Superordinate and subordinate concepts are present and valid.	Most but not all are present and valid	Some are present and valid.	Few are present and/or valid. Several subordinate concepts are missing.	Hierarchy is missing or invalid.
Cross links	All are valid and non trivial. Strong evidence of higher level of thinking/ in-depth conceptual understanding.	Most are valid and non trivial. Some evidence of higher level/ in-depth conceptual understanding.	Some valid but trivial. Some evidence of higher level / in-depth conceptual understanding.	Most are invalid or trivial. Little evidence of higher level / in-depth conceptual understanding.	Missing or invalid. No evidence of higher level / in-depth conceptual understanding.
Examples	Complete set; valid, illustrative, and significant.	Incomplete set; but most are present and valid, illustrative and significant.	Incomplete set; but some are present and valid, illustrative and significant.	Incomplete set; few are present and valid, illustrative or significant.	Missing or invalid.

Rubric for scoring concept maps adapted from Novak & Gowin, 1984 and Shaka & Bitner, 1996

Appendix H: Treatment of Cognitive Conflict with Simulations Class

1. **EPE Concepts (A Session of One Group for Sample)**

At the beginning, all the groups of students in the CCS class were inquired to predict the values of electric potential of positive and negative charges at different points say 1m, 2m from the point charges. They were asked to show their response on a piece of paper.

However, the students' predictions were diversified. Some said that to calculate electric potential, the given quantities are incomplete and they need to have another charge to measure the distance between them. Others said that the mass of the charge was not given and therefore they couldn't calculate the potential. There were also several students that attempted to multiply a charge by a distance to calculate electric potential. Few students used the formula for the electric potential and calculated its value. However, they consider electric potential to the right of and above the point charge as positive, while they consider electric potential to the left of and below the point charge as negative.

The students' predictions were in agreement with their already identified and diagnosed pre intervention conceptions about electric potential. The students who needed to add another charge to calculate the electric potential considered electric potential as a Columbic force. The students who needed the mass of a charge to determine the electric potential viewed electric potential as a gravitational potential energy. Those who multiplied a charge by a distance had ideas of direct relationship between electric potential and distance. Some students who attempted to estimate the electric potential using the formula failed to understand its scalar nature.

After their prediction, they were told to activate the *grid*, *show numbers* and *tape meters* options buttons on the right-hand-side of the *Charges and Fields* application (See Figure 3.1). Then, they were asked to place a positive charge in grid's center using their PC mouse. As shown in figure, the amount of charge on each point charge was $1nC$. Then, the students were asked to measure the distance between a positive point charge and point(s) in the field at which they were interested to calculate electric potential (see Figure H1). They were asked to repeat the same procedure with a negative point charge (see Figure H2). Then, the conditions for cognitive conflict of the classical conceptual change model were attempted to guide their conceptual learning as follows.

Dissatisfaction: Firstly, to *dissatisfy* the students with their existing alternative conceptions and then increase the status of the desired scientific conceptions, the students were asked to check their predictions by dragging the *potential tool* on different points around the charge. They were asked to do so for both negative and positive point charges. But, for most of the students, what they measured and plotted were different from what they predicted.

Figure H1: Electric potential and equipotential curves around a positive charge that the students were guided to draw with simulation after their prediction.

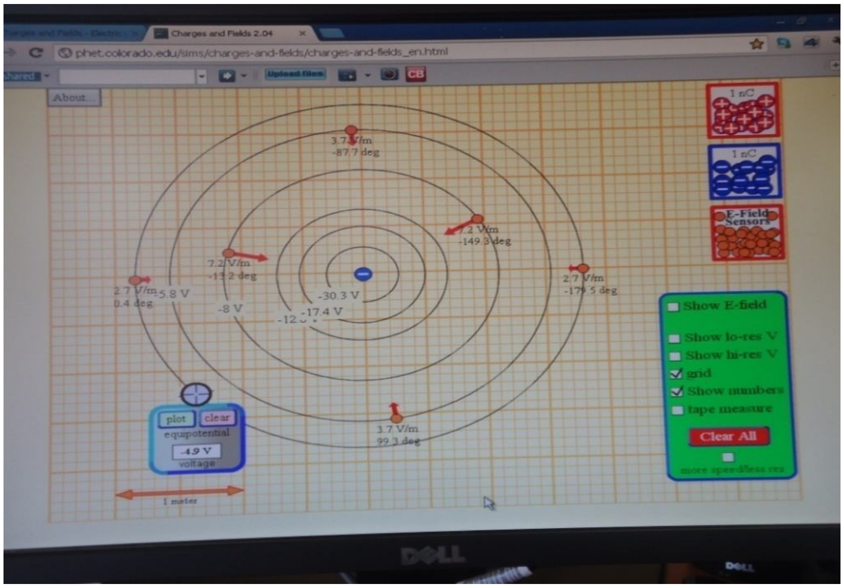


Figure H2: Electric potential and equipotential curves around a negative charge that the students were guided to draw with simulation after their prediction

Intelligibility: Secondly, for the *intelligibility* of the desired scientific conceptions (the concept of electric potential) the interactive simulation helped the students to clearly measure the electric potential and plot the curves. In fact, without the use of the simulation the concept of electric potential is abstract and difficult to understand and make it intelligible for the students.

The researcher further asked the students about the potential curves they had plotted. What was represented by the curves? Some of the students replied, 'it represents electric field.' Others said, 'it is electric potential line.'

Though the students observed the difference between their prediction and the simulation result about the concept of electric potential, most of them were unable to explain the quantities the curves represented on the simulation.

Plausibility: For the plausibility of the electric potential concepts they learned, the researcher asked them to crosscheck the reading from the *potential tool* of the simulation with the calculated value of electric potential (the distances were measured with the *tape meters* of the application). In addition, to increase the degree of plausibility of the concept, they were made to measure electric potential at different points in the *playing field* of the simulation and plot potential curves using the *potential tool* (See Figure H3).

Fruitfulness: For *fruitfulness* of the scientific concepts, the students were asked to extend their conceptual knowledge by running the simulation for two and more point charges. First, they took two and more positive charges then two and more negative charges and lastly by taking two and more positive and negative charges.

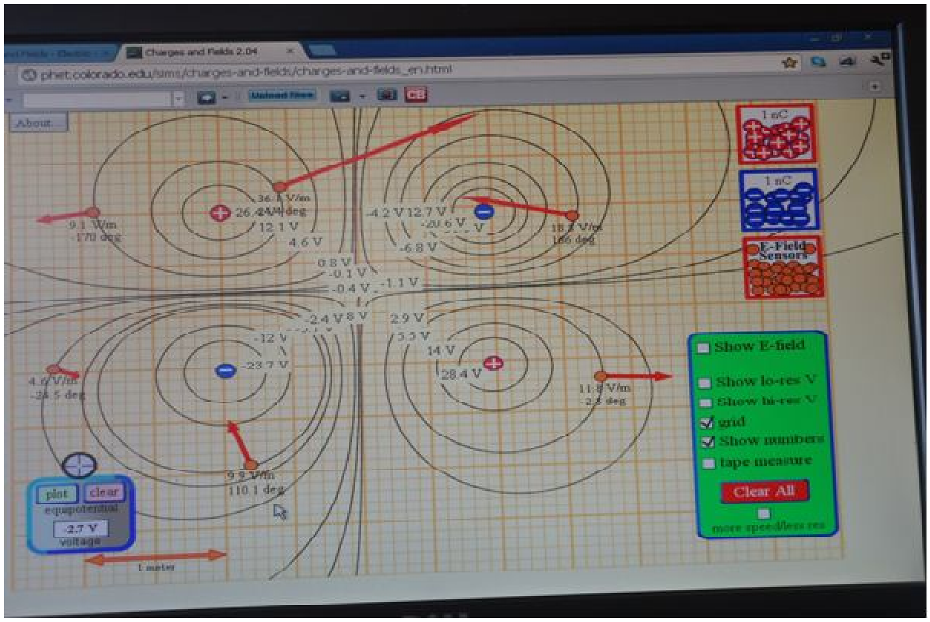


Figure H3: The students were made to draw electric potential and equipotential curves around several charges with simulation

However, only few students in each group were able to extend their knowledge of electric potential of a single point charge to several point charges. This was because of the inconsistency and diversity of the students' alternative conceptions at the beginning of the treatment. Their situation before the treatment made them not to be fully dissatisfied with their existing conceptions and then not to accept and apply the new concept as desired.

2. EMI Concepts (A Session of One Group for Sample)

The main concept of the electromagnetic induction is the production of induced current. For this reason, the CCS class was treated with the most complete panel (only the last panel), the *generator* panel (see Table H4), of the Faraday's Electromagnetic Lab simulation to initiate cognitive conflict between their existing conceptions and the scientific conceptions. Thus, at the beginning, all the groups of students in the CCS class were required to predict the cause for induced current/induced emf. The students' predictions were diversified alike to the pre intervention results. The dominant alternative conceptions depicted from their predictions were

- Magnetic field produces induced current,
- Magnetic field lines produce induced current,
- Magnetic flux produces induced current,
- Current implies induced emf and
- Magnet implies induced emf.

The students failed to understand the cause for induced emf/induced current. The cause for induced current is explained by the Faraday's Law of induction. This Law states that the time rate of change of magnetic flux causes induced emf that derives induced current in a closed loop of conductor.

Dissatisfaction: After their prediction, they were told to run the Electromagnetic Lab simulation by activating the options *show field*, *show compass*, *show field meter*, *change number of loops*, *change loop area* and *change magnetic field strength* (See Figure 3.2). Then, to *dissatisfy* the students with their existing alternative conceptions and then increase the status of the desired scientific conceptions, the most complete panel (the *generator* panel) of the Electromagnetic Lab that can fully display Faraday's Law of induction, was selected. The students were then asked to check their predictions by changing the options of the simulation and noticing the *field meter* reading at a point and different points in the simulation field.

First, in order to dissatisfy them with their existing conceptions, they were asked to put the turbine off and then observe the situation of the simulation. There was a magnet and a magnetic field in the coil. They measured the presence of magnetic field with the *field meter*. They observed the presence of magnetic field lines by activating the *show field* button of the simulation. Besides, there was a magnetic flux due to the presence of a magnetic field in the area of the coil. However, there was no induced emf or and consequently no flow of electrons observed in the coil.

Next, to increase the status of the scientific conception, the students were required to put the turbine on and then observe the event as shown in Figure H4. By using the *field meter,* they noticed the change of magnetic field in the coil as a result of the rotation of the magnet by the turbine. Consequently, they observed a flow of simulated electrons which was an indication of the presence of an induced current in the coil. Also, they observed deflection of the simulated *voltage reader* and/or the *bulb* which indicated the presence of the induced emf.

Figure H4: Faraday's Law induction shown by simulated generator to dissatisfy students' alternative conceptions

Intelligibility: For the *intelligibility* of the desired scientific conceptions (the concept of induced emf/induced current) the interactive simulation helped the students to clearly observe how the induced current is produced in a coil. The interactive simulation was easily run and then controlled to see the resulted change and the effect caused. In fact, without the use of the simulation the concept of induced current is abstract and difficult to understand and will not make it intelligible for the students.

However, the students' conceptual knowledge about the concepts of electricity and magnetism in general and the concept of electromagnetic induction in particular were low as shown in the pre intervention result. Thus, this situation of the students limited the degree of intelligibility to understand the scientific conceptions. This limited degree of intelligibility of the scientific conceptions was noticed because the students' group discussions about the concepts were low during their learning. In other words, the students were not well engaged into interactions due to their low conceptual knowledge. However, most of the students' discussions were emphasized more to the simulations rather than to the concepts.

Plausibility: For the plausibility of the induced current and/or induced emf scientific conceptions, the researcher asked the students to vary the rotation speed per minute (RPM) of the turbine and then take the reading of the magnetic field variation inside the coil with the application of the *field meter*. At the same time, they were asked to observe the reading on the voltmeter attached to the coil. They were then supported to compare the value of the emf from the reading of the voltmeter with its value calculated with the help of the formula for Faraday's Law of induction.

Fruitfulness: For *fruitfulness* of the scientific conceptions induced current and/or induced emf, the students were asked to extend their conceptual knowledge by activating the different contextual panels of the Faraday's Electromagnetic Lab Simulation. These were the moving of a magnet into and out of a coil and viewing of the induced emf, varying of current in one coil and then observing the voltage induced in another coil, varying of the number of turns of the coil and then viewing the emf induced and varying the area of the coil and viewing the emf induced.

Appendix I: Treatment of Cognitive Perturbation with Simulations Class

1. **EPE Concepts (A Session of One Group for Sample)**

Undertaking phase: At the beginning, alike to the CCS class, all the groups of students in the CPS class were asked to open the *Charges and Fields* application (See Figure 3.2). First they were told to activate the *grid*, *show numbers* and *tape meters* options buttons on the right-hand-side of the application. Second, they were asked to place a positive charge in grid's center using their PC mouse and measure the value of electric potential at different points by measuring the distance between the point charge and different points in the *playing field*. In addition, they were inquired to drag the *potential tool* around the playing field to measure electric potential and plot potential curves. Moreover, they were asked to repeat the same task for a negative charge after removing a positive charge from the playing field.

In this phase, the researcher's main role was giving social support and working with them, but not to elicit conflict with their ideas, while they were manipulating variables in the interactive simulations.

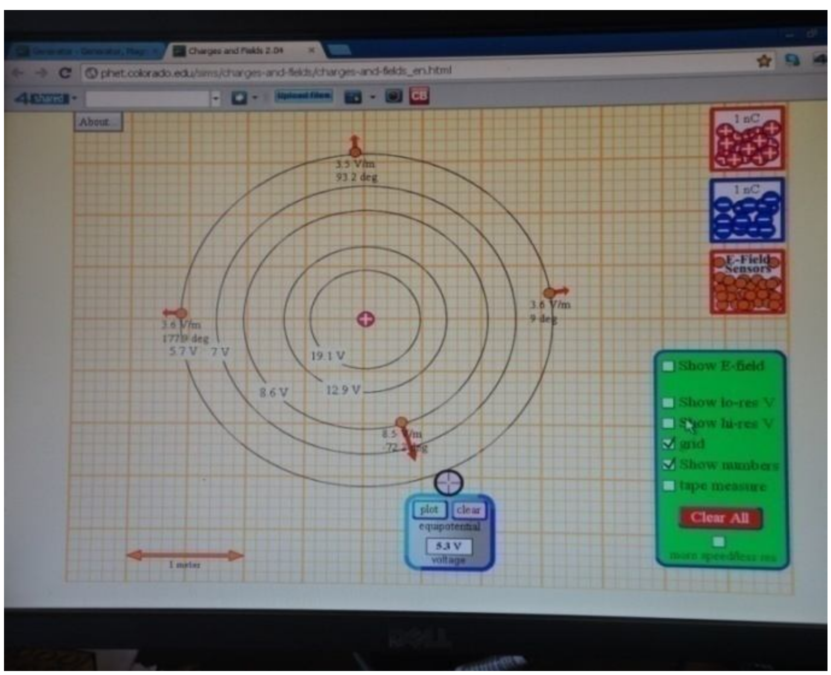


Figure I1: Students were guided to manipulate electric potential of a positive charge and equipotential curves

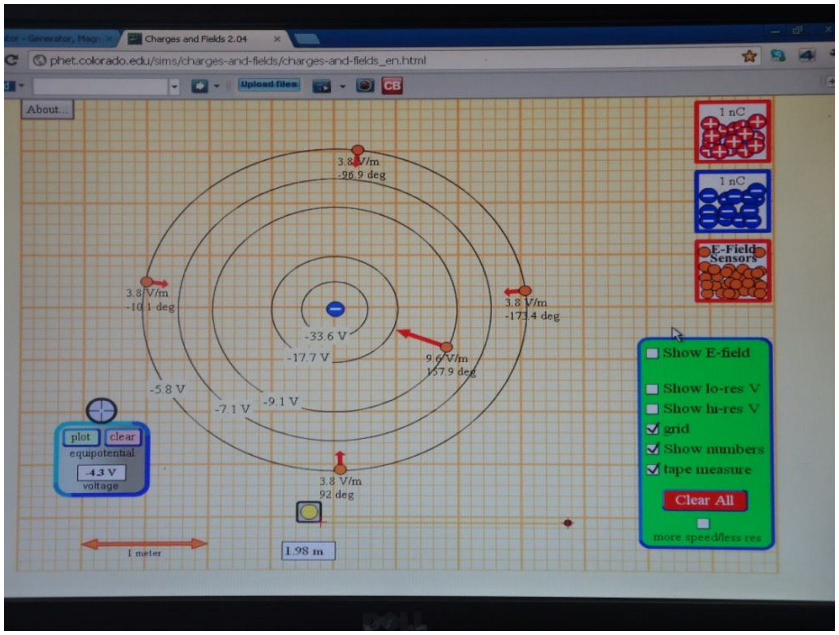


Figure I2: Students were guided to manipulate electric potential of a negative charge and equipotential curves

Presentation phase: This was an appropriate situation to identify students need to support their learning. In short, it was used to identify the difficulties which impeded their learning and needed the instructor's support in the form of cognitive perturbation. For example, students in one of the groups presented their undertaking as shown in Figures E1 & E2.

They explained their understanding of what they measured and plotted as follows. 'We (the students) measured potential of a charge at different points and plotted curves of the electric field around a positive and a negative charge one after another. The electric potential for a positive charge is positive, but it is negative for a negative charge. As the distance from a charge increases, potential decreases.'

What does the positive or negative sign of the electric potential represent? The instructor asked. Some students said, 'positive represents repulsion, while negative represents attraction.'
From the above students' explanation, two ideas that needed support (cognitive perturbation) were identified. The first idea was their interpretation of potential curves (equipotential lines) as electric field lines, because they said, 'we plotted electric field.' The second idea was their

consideration of electric potential as a force: 'positive represents repulsion, while negative represents attraction.'

The instructor thanked the students for their presentation and then asked the following questions to guide them step by step towards scientific conception of electric potential.

The instructor: You put positive charge and took measurements, and then you replaced by a negative charge and did the same. How could attraction or repulsion be happen?

The students looked and laughed at each other. Then, one of the group members said, 'we don't know what we are doing.' He continued, 'you know attraction or repulsion is for force, but we measure electric potential.' Another student said, yes! 'Force is between two charges, but what we measure using the simulation is for only one charge.'

The instructor: So, what do the signs (+) and (-) represent?

A student: 'The sign comes from the charges. Negative electric potential is for negative charge and positive electric potential is for positive charge.'

Another student: 'Before this simulation I thought electric potential as a vector because of the signs positive and negative. Now, it can't be a vector.'

The instructor: So, who can tell me what the signs represent.

The group members did not speak for some minutes. Their silence indicated their failure to clearly understand the electric potential in relation to signs. Then, the researcher instructed them to put two opposite charges at some distance between them, say 1m (measured by simulated *tape meter)*, and then measure electric potential at different points: between the two charge, to the right and left of the positive charge, and to the right and left of the negative charge (See Figure I3).

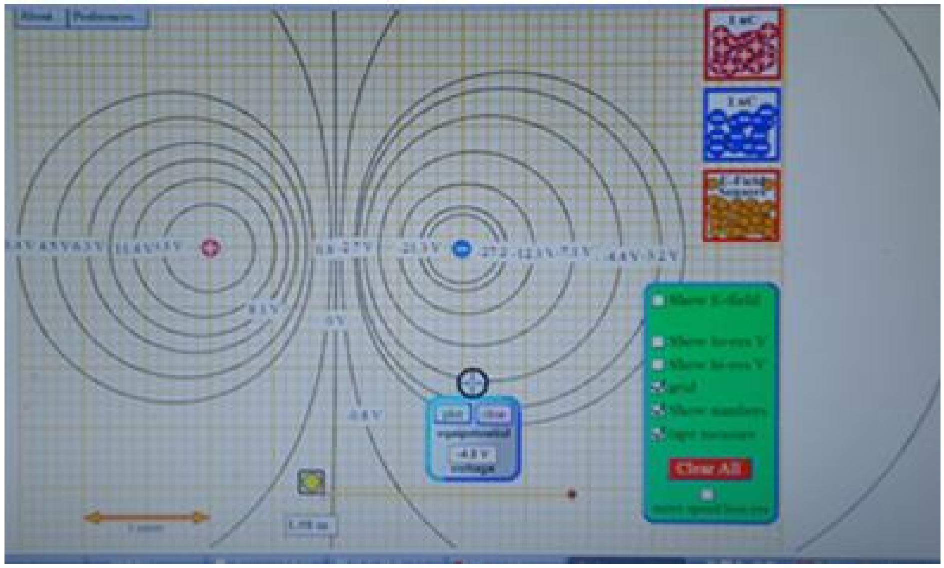


Figure I3: Students' manipulation of electric potential of two point changes

After the students accomplished the task, the instructor asked what they have noticed in the simulation.

One of the group members said, representing most members' consensus, 'we see that near the positive charge and far from the negative charge electric potential is positive. Near the negative charge and far from the positive charge the electric potential is negative. As we move the *potential tool* from positive to negative, the electric potential is decreasing and becomes zero. Past zero electric potential is becoming more negative.'

From this explanation, it was thought that majority of the students have scientific understanding of electric potential, like positive (high) electric potential, negative (low) electric potential and a condition at which electric potential becomes zero.

Another students' idea that impeded their learning was their supposition of electripotential lines as electric field lines. To support their learning towards replacing this idea and enhancing of the scientific concept, the instructor asked the students to activate the *E-field* and *field sensor* buttons (See Figure I4) to notice the electric field magnitude and direction.

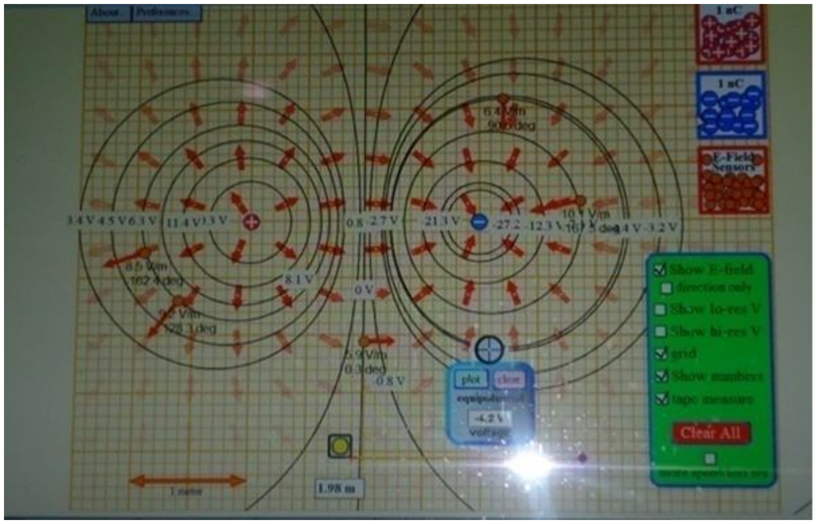


Figure I4: Students' manipulation of equipotential lines and electric field lines

With the help of these detectors, the students easily noticed that the electric field lines are out of the positive and into the negative charges. In addition, they observed that the lines for electric potential and the lines for electric field are perpendicular at a point.

Refining phase: This was the phase after presentation in which the students were to incorporate the comments from the discussion and redo the task the researcher inquired to enable them correct their difficulties. Also, the researcher checked each group's work and continued his social support and cognitive perturbation in their contextual needs so that they would rectify their alternative conceptions.

In this phase, the students repeatedly manipulated the simulations and measured electric potential and potential curves for: a positive change, a negative charge, two positive charges, two negative charges, a negative and a positive charge and several like and unlike charges. The utility of guiding the students in this phase was to enable them stabilize their conceptual understanding of the electric potential concepts.

2. EMI Concepts (A Session of one Group Sample)

In order to suit the Faraday's Electromagnetic Lab simulation for the CPS class, the four steps (four panels) of the simulation were used as scaffold to support the students learning from their preconceptions towards scientific conceptions of EMI concepts.

Undertaking phase: At the beginning, all the groups of students in the CPS class were asked to open the Faraday's Electromagnetic Lab simulation. Then, they were to interact with the four panels of the simulations step by step starting from a simple *bar magnet* to the inclusive *generator* simulation.

Undertaking Phase with a Bar Magnet: This was the first of the undertaking phase in which the students were instructed to move the bar magnet and then observe the reading of magnetic field strength from the *field meter* at a point as well as different points in the field (see Table I5).

Figure I5: Magnetic field strength of a bar magnet measured with the field meter

Presentation Phase: The students explained their observation as follows. When the magnet was not moved the reading of the field meter was constant. But, when the magnet was moving forward the magnetic field strength was increasing. When the magnet was moving backward the magnetic field was decreasing.

The instructor asked the students with what position or point they had measured motion of the bar magnet?

The students: We mean forward and backward of the magnet motion. Forward magnet motion increases magnetic field strength, while backward magnet motion decreases magnetic field strength.

From this students' explanation, the instructor noticed that the students were not aware of the position they were measuring the magnetic field. In other words, the instructor noticed where their gap in understanding lay to give them cognitive perturbation and help them to rectify their learning. Thus, the instructor inquired the students to shift the position of the *field meter* to different points and then measure the magnetic field strength in both cases (when the magnet was at rest or in motion).

The students: They attempted to address the researcher's task of moving the *field meter* and observing its reading, keeping the *field meter* at a point and then moving the magnet. After they undertook the task (the task posed by the researcher as a cognitive perturbation) they were able to explain that they measured magnetic field with respect to position of the magnet at a point (field point) in the space. That field point is the point where they placed the *field meter,* the detector.

Undertaking Phase with Pickup a Coil: In this part, the second panel of the Faraday's Electromagnetic Lab simulation was used (see Table I6). The undertaking phase in this case was more composite than in the previous *bar magnet* only simulation. In this phase, the students were instructed to move the bar magnet into and out of the coil and observe the *field meter* reading at the center of the coil. Simultaneously, they were asked to observe the voltage reading or alternatively the bulb connected to the coil.

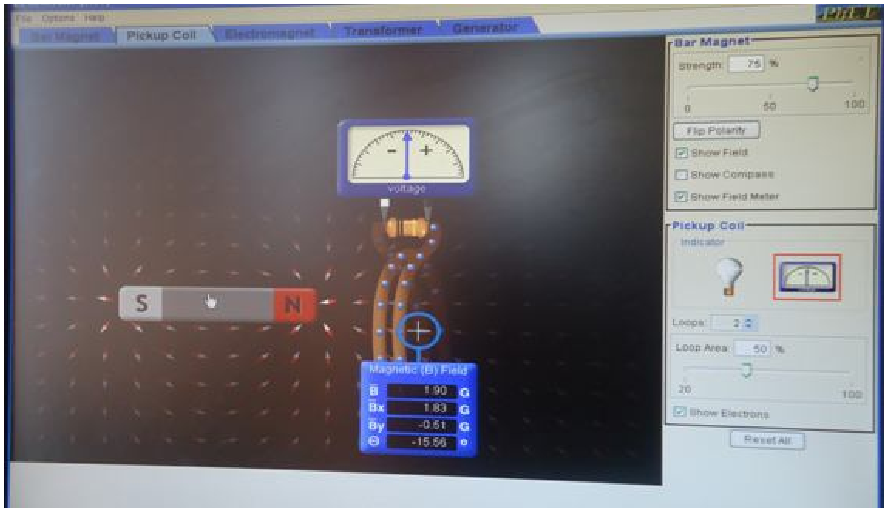


Figure I6: Relating magnetic field strength variation with the deflection of the voltmeter

Presentation Phase: The students interacted with the simulation as they were instructed and then explained what they had observed in the simulation as follows. 'When the magnet moves to the right into the coil, the voltage is deflected to the left. When the magnet moves to the left out of the coil, the voltage is deflected to the right.'

The instructor asked, what caused this deflection of the voltage reader?
The students said, 'It is the motion of the magnet.'
The students still failed to understand how an induced current/voltage can be produced in a coil. Thus, the teacher posed additional cognitive perturbation he believed will help them understand the concept.

The instructor instructed them to place the bar magnet inside the coil. Then, he asked them to vary the strength of the magnetic field using the simulated *change the field strength* option and then observe the reading of the *voltage reader*. The students' explanation follows.

Students' explanation: The students' said that an increase or decrease of the magnetic field strength results a deflection of the voltage reader. We understand that moving a magnet with respect to a point can result in a variation of magnetic field strength at that point.

Undertaking Phase with Electromagnet and Transformer: The students' were asked to vary the voltage of the battery connected it to the coil of an *electromagnet* and observe the corresponding magnetic field strength with the *field meter* (see Table 17). They were also required to run the *transformer* panel and then observe the readings of the *field meter* and the *voltage reader*.

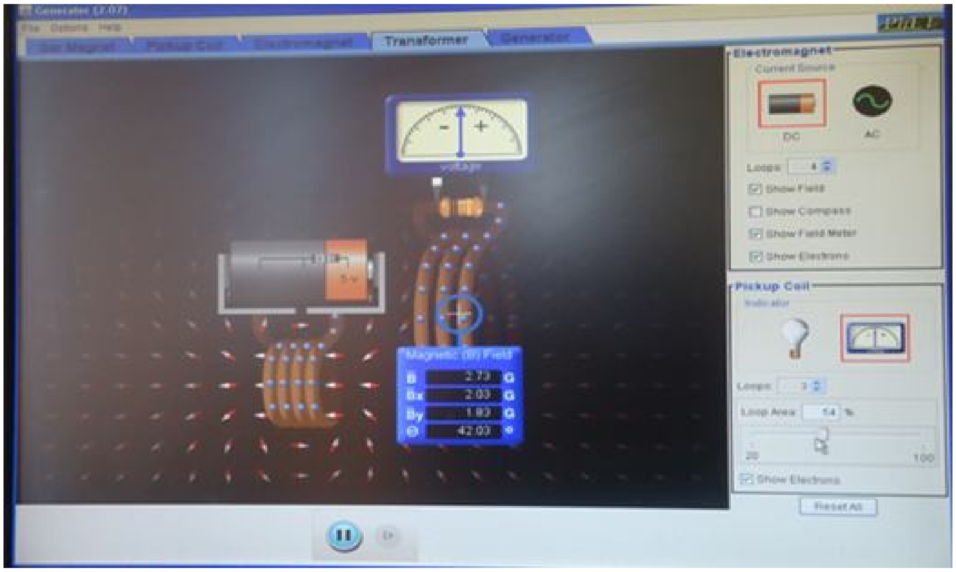


Figure I7: Relating magnetic field strength variation with the deflection of the voltmeter

Students' Explanation: The students explained what they had observed as follows. When we put the voltage of the battery to some value to the right (they meant it positive) there is some positive magnetic field as read with the *field meter*, when the voltage of the battery is move to the left (they meant it negative) the magnetic field is negative. When the voltage of the battery is kept at zero the *field meter* read zero.

The instructor: What do you notice if you continuously changing the voltage of the battery? This question was asked in order to support the students (give cognitive perturbation) into a more scientific conception. This means to enable them to understand that a variation of current in a coil can result in a variation of magnetic field strength, which is a precondition for an induced emf.

The students: For some minutes, the students interacted with the simulation and gave their response to the question as follows. 'When we increase or decrease the voltage of the battery, similar conditions are observed, like the deflection of the voltmeter. The directions of the deflections are opposite.'

The instructor: Can you relate the change of the battery's voltage to the current in the first coil and consequently relate this change of current in the first coil to the deflection of voltmeter connected to the second coil?

Students' explanation: When voltage of the battery is the same (constant), the current in the coil is also constant and no deflection of the voltmeter connected to the second coil. But, when current in the first coil is changed due to the change of the battery's voltage, then there is a deflection of the voltmeter connected to the second coil.

The instructor: Who can tell me the name of this deflecting voltage?
The students: Some students said, 'it is simply a voltage'.
The instructor: What type of voltage?
The students: 'Just the same as voltage of the battery supplied to the first coil.' One of the students said, 'it is a potential difference.' Another one added, 'it is an induced voltage.'

The instructor: Why do you call it induced voltage?
A student: I remember the equation of induced voltage from school physics learning. But, I haven't understood it like this at that time. I learned in theory. Now, the way we were taught helps me to understand.

As noticed from the students' explanation, there were only a few of them able to understand the concept of induced current. Though the mechanism used (cognitive perturbation) was supporting the students learning step by step, their low conceptual knowledge had hindered the progress of their concept learning. Because the students still have alternative conception of considering an induced voltage as a potential difference.

Refining phase: This is the last phase in which the students would incorporate the comments from the discussion and redo the task the researcher inquired to enable them correct their difficulties. Also, the researcher checked each group's work and continued his social support and cognitive perturbation in their contextual needs so that they would rectify their alternative conceptions.

In this phase, the last inclusive panel of *Faraday's Electromagnetic Lab* simulation, the *generator* simulation, was used by the students to repeatedly manipulate the simulations and observe the induced emf (See Figure I8). The students were guided to run the turbine of the generator at different RPM (rotations per minutes), varying the strength of magnetic field from minimum to maximum, changing the number of turns and the area of the coil. The guiding of the students in this phase was to enable them stabilize their conceptual understanding of the induced emf concept.

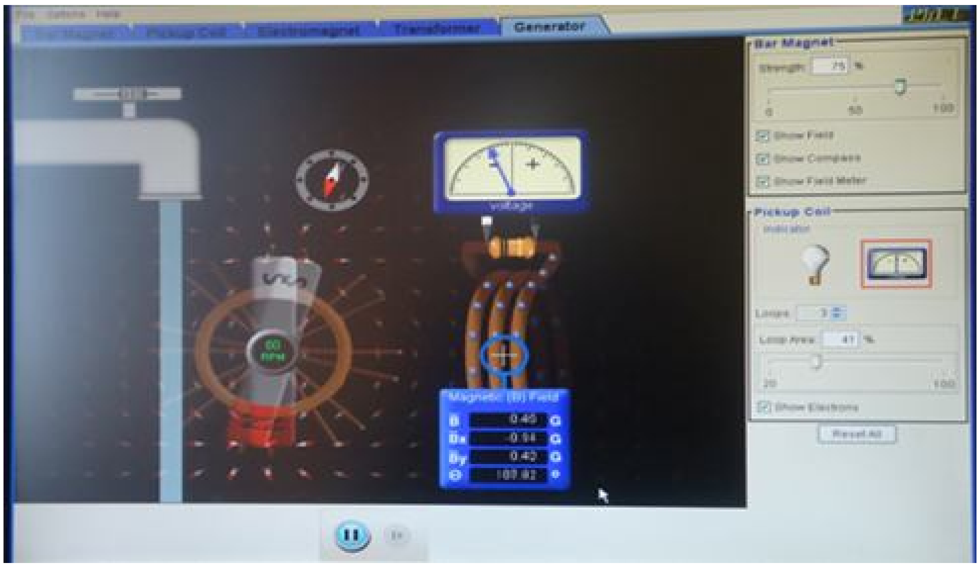


Figure I8: Hydroelectric generator simulation used for refining students understanding of induction