

The impact of a teaching sequence on teachers' conceptual development in electrodynamics

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DECLARATION

I the undersigned, hereby declare that the work contained in this dissertation / thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

A handwritten signature in blue ink, consisting of a stylized 'H' followed by a cursive flourish, positioned above a horizontal line.

Handtekening / Signature

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ABSTRACT

This study explored the impact of a teaching sequence on physical sciences teachers' conceptual development in electrodynamics, using simulations and experiments. The teachers' pre-conceived knowledge in electrodynamics was explored to try to reconstruct, refine and improve the content knowledge of electrodynamics, by filling knowledge gaps and addressing alternative conceptions. In view of the constructivist theory, computer simulation and practical works were to serve the purpose for effective teaching and learning for conceptual development. Physical sciences teachers were sampled as the experiment and control group. The teachers of Kgetleng circuit in Ngaka Modiri Molema district (North West of South Africa) were sampled for this study because the researcher had easy access to the group as she directly worked with groups. Sixteen teachers (participants) formed the experiment group, and fifteen formed the control group, giving a total of thirty-one teachers (participant)s. Both groups were work-shopped for three days to enable the researcher to best understand the research problem.

The empirical study commenced with the experimental and control groups writing the same pre-test in order to determine common conceptual problems that needed attention in the intervention. Two groups were then exposed to the same content organised in a conceptual development teaching sequence that followed the historical development of electrodynamics to a great extent. Although the teaching approach was teacher-centred, the teaching methods entailed concept refinement for improved understanding. The main difference between the control group and the experimental group was that simulations and practical work were infused in the sequence presented to the experimental group.

The influence of the intervention with the experimental group was determined using both quantitative and qualitative data collection and analyses. The quantitative data was embedded within the qualitative experimental design. Collection of data occurred in three phases, and that was; before intervention, during intervention, and after intervention. Participants' written reports, questionnaire and video-recorded activities complemented each other and were analysed. After the intervention, the same questionnaire that was used as a pre-test was used as a post-test to measure the impact of the teaching sequences. Learning gained was measured after intervention to

compare the impact of interventions. The improvement of content knowledge for the experimental group was attributed to the use of computer simulations and experiments. The results necessitated the recommendation that computer simulations and practical work be used to address the needs and demands of the subject. The approach is relevant for the learning and teaching of physical sciences, and impacted positively in the improvement of knowledge in this study.

KEY WORDS

Computer simulations; practical work; electrodynamics (electromagnetism and induction); intervention; teaching sequence; concept development; knowledge improvement.

OPSOMMING

Hierdie studie het die impak van 'n onderrigvolgorde ondersoek, met behulp van simulaties en eksperimente op fisiese wetenskappe onderwysers. Die onderwysers se vooropgestelde kennis in elektrodinamika is ondersoek om die inhoudskennis van elektrodinamika te rekonstrueer, te verfyn en te verbeter deur leemtes in hul kennis te vul en alternatiewe konsepte aan te spreek. In die lig van die konstruktivistiese teorie het rekenaarsimulasie en praktiese eksperimente die doel gedien vir effektiewe onderrig en leer vir konseptuele ontwikkeling. VOO-onderwysers is as die eksperimentele en kontrolegroep op die proef gestel. Die onderwysers van die Kgetleng-baan in die Ngaka Modiri Molema-distrik (Noordwes van Suid-Afrika) is vir hierdie studie op die proef gestel omdat die navorser maklike toegang tot die groep gehad het, aangesien sy direk met groepe gewerk het. Sestien onderwysers (deelnemers) het die eksperimentele groep gevorm en vyftien het die kontrolegroep gevorm, wat altesaam dertig onderwysers (deelnemers) gegee het. Beide groepe is vir drie dae aan werkwinkels onderwerp om die navorser in staat te stel om die navorsingsprobleem te verstaan.

Die empiriese studie het begin met die eksperimentele en kontrolegroepe wat dieselfde voor-toets geskryf het om algemene konseptuele probleme wat met intervensie aandag moes geniet te bepaal. Twee groepe is dan blootgestel aan dieselfde inhoud wat georganiseer is in 'n konseptuele ontwikkelingsonderrigvolgorde wat die historiese ontwikkeling van elektrodinamika in 'n groot mate gevolg het. Alhoewel die onderrigbenadering onderwysergesentreerd was, het die onderrigmetodes 'n beter

begrip van kognitiewe verfyning en kognitiewe konflik behels. Die hoofverskil tussen die kontrolegroep en die eksperimentele groep was dat simulasies en praktiese werk in die volgorde wat aan die eksperimentele groep voorgelê is, toegedien is.

Die invloed van intervensie met die eksperimentele groep is bepaal deur gebruik te maak van beide kwantitatiewe en kwalitatiewe data-insameling en ontledings. Die kwantitatiewe data is ingesluit binne die kwalitatiewe eksperimentele ontwerp. Versameling van data het in drie fases plaasgevind, naamlik voor intervensie, tydens intervensie, en ná intervensie. Deelnemers se geskrewe verslae, vraelyste en video-opnames van hul aktiwiteite het mekaar aangevul en is geanaliseer. Ná intervensie is dieselfde vraelys wat as 'n voor-toets gebruik is, gebruik as 'n na-toets om die impak van die onderrigvolgorde te meet. Die onderrig wat opgedoen is, is gemeet ná intervensie om die impak van intervensies te vergelyk. Die verbetering van inhoudskennis vir die eksperimentele groep is toegeskryf aan die gebruik van rekenaarsimulasies en -eksperimente. Die resultate het die aanbeveling vereis dat rekenaarsimulasies en praktiese werk gebruik word om die behoeftes en vereistes van die vak aan te spreek. Die benadering is relevant vir die leer en onderrig van fisiese wetenskappe en het 'n positiewe impak gehad op die verbetering van kennis in hierdie studie.

SLEUTELWOORDE

Rekenaarsimulasies; praktiese werk; elektrodinamika (elektromagnetisme en induksie); intervensie; onderrigvolgorde; konsepontwikkeling; kennisverbetering.

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ACRONYMS

AC	Alternate current
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education
DC	Direct current
CG	Control group
EG	Experiment group
ELRC	Education Labour Relation Council
EMF	Electro motive force
FET	Further Education and Training
ICT	Information communication technology
LAB	Laboratory
MSTS	Mathematics, science and technology services
NCS	National Curriculum Statement
NTL	Non-traditional lab
NW	North West
PHET	Physics Education Technology
PMDS	Performance Management and Development Systems
QUAL	Qualitative
QUAN	Quantitative
RE	Real experiments
SBA	School based assessments
TL	Traditional lab
VE	Visual experiments
VSDT	Village, Small Dorpie (town), Township

CHAPTER 1: ORIENTATION AND RESEARCH DESIGN

1.1 MOTIVATION OF STUDY AND DISCUSSION OF RESEARCH PROBLEM

According to West (2009), Planinic (2006) and Hekkenberg, Lemmer, and Dekkers (2015:35), few investigations have been performed on difficulties that learners have on concepts in electricity and magnetism, but even less research have been conducted on electrodynamics. This is further confirmed in the bibliography of research studies on science learners' conceptions (Duit, 2009), according to which studies on learners' ideas in electromagnetism and electrodynamics are scarce as compared to numerous reports on learners' understanding of basic mechanics in physics. Science research studies on subject matters related to electrodynamics focused mainly on learners' understanding of circuit electricity (Dega, Kriek & Mogese, 2013:678) or electric and magnetic fields (Duit & Treagust, 2003:672) and not on electrodynamics applications. Furthermore, concepts that underlie electrodynamics, such as electromagnetic induction have not yet been studied sufficiently (Dega *et al.*, 2013:679).

Electromagnetism, the foundation of electrodynamics, is one of the key topics in the teaching and learning of physical sciences in South Africa. The topic is highly weighted in the Curriculum and Assessment Policy Statement (CAPS) and for that reason it needs serious and urgent attention, especially since learners are not performing well in this section (DoE, 2013:175). It was pointed out in the National Senior Certificate (NSC) examinations diagnostic report that learners' performance was poor in electromagnetism (DoE, 2013:175) and was further recommended that Subject Education Specialists (SES) must provide teacher development workshops on these sections (DoE, 2013:173-201). The reason for underperformance of learner might be attributed to, as proposed by Kriek and Grayson (2009:185) teachers' alternative conceptions and knowledge gaps and this to be causal factors to the poor state of physical sciences education in South Africa.

Solution to such challenges is slim since few studies focused on the understanding that science teachers had on the topic (Kriek & Grayson, 2009; Burgoon, Heddle & Duran 2010). Moreover, teachers and learners seem to have similar alternative

conceptions. This underlines the impact that teachers would have on learners' learning and Hekkenberg, Lemmer, and Dekkers, (2015:35) consequently stressed that attention should be paid to teachers' scientific understanding of electromagnetism and not only learners'. Bagno and Eylon (1997:735) also believed that poor performance and understanding at school may be related to teachers failing to let learners experience the relevance of sciences in everyday life. They further pointed out teachers' alternative conceptions as another major cause of learners' poor performance. Such alternative conceptions form strong knowledge structures that are used inconsistently, are not easy to cure and can create gaps in learners' scientific knowledge. Knowledge gaps are theoretical structures formed out of a fragmented knowledge base and concepts that are not interrelated (DiSessa, 1988; Guisasola, *et al.* 2004:450).

Buczynski and Hansen (2009:600) pointed out that most teachers in secondary school are usually not adequately ready to confidently teach content matter in physical sciences. An effect of teachers' insufficient or incorrect knowledge is the physical sciences foundation that is not properly laid in schools. This is in agreement with Bagno and Eylon (1997:735) who attributed poor understanding of topics such as electrodynamics in first year tertiary learners to inadequate teaching and learning at school. They indicated that learners go into higher institutions without proper background of topics that were laid prior to tertiary studies. Physical sciences teachers should thus be equipped with content knowledge necessary to provide quality instruction as well as knowledge of how to deal with learners' conceptual problems. Teachers' conceptual deficiencies and alternative conceptions are carried to schools and get transferred to learners and the problems get carried to the tertiary institutions (Gunstone & Thong, 2007:1). Therefore, first year university learners often struggle to change their incorrect mental models into correct but complex and abstract representations. Most of them form or retain their incorrect models and alternative conceptions from basic education (Bagno & Eylon, 1997:735).

Several research studies found that university physics learners' struggle with physical sciences, and is more prevalence in electromagnetism (Beer, 2010:25; Bagno and Eylon, (1997:726-736); Planinic (2006:1143-1147); Planinic (2006:1143-1147) reported a study conducted with tertiary learners and the outcomes revealed

that learners mainly had difficulties in conceptual areas of electricity and magnetism. The most difficult concept found amongst two groups of learners was electromagnetic induction. Another university study in Turkey and England was conducted by Saglam and Millar (2006:1-18) and conclusions was also reached that learners have a poor understanding of the basic concepts of electrodynamics.

Wood (2008:207-209) indicated that most of the teachers who participated in his study taught at a time when they were expected to decide what ought to be learned, how it must be learned and when it should be learned. In this paradigm, the traditional method was the main teaching and learning method. Teachers' knowledge after a traditional high school course indicated insufficient knowledge in electromagnetism (Bagno & Eylon, 1997:730). This seems also to be the case in South African schools (Lemmer *et al.*, 2008). The outcomes of the results suggested that addressing knowledge gaps of teachers should make an impact and a valuable contribution to science education in South Africa.

Physical sciences teachers in the entire world are still trying to find ways to stimulate learners and teach them in a manner that will improve physical sciences learning to make it more accessible (Ogborn, 2000:301). Orgborn (2000) stated that several ways to accomplish this have been recommended in different research studies and include the use of experiments, simulations, multimedia, demonstrations, research projects, etc. He suggested that with the support of cheap hands-on equipment, also by involving media-rich software for simulations and visualisations, the way physical sciences is taught can be transformed. Computer simulations and practical works have the potential to create learning environments that are different from traditionally focussed teaching.

According to Koponen and Mäntylä (2006), practical work is essential and fundamental in physical sciences teaching and learning. It can guide learners to constructive and accurate conceptual development and at the same time helps them to turn out to be knowledgeable and competent in science (O'Brian, 1991:934). It was also found that learners attain better and have improved knowledge after instruction with computer-based activities or virtual experiments (VE) as compared to verbal (normal) traditional teaching methods that does not enhance a holistic, real-life perspective when learning (Jonassen & Reeves, 1996). Thus, virtual experiment

(VE) can be used in some contexts to provide reliable laboratory experiences that are not substantially different from real experiment (RE)

According to Brinson (2015:218) contemporary practical work entails traditional laboratories (TL) and/or non-traditional laboratories (NTL). TLs are also called hands-on (Ma & Nickerson, 2006) or real experiments (Zacharia, 2007). As indicated above, NTL can be performed virtually or remotely and may incorporate computer simulations and other online learning tools. Ma and Nickerson (2006:5, 6) describe hands-on laboratories as involving a “physically real investigation process” and virtual labs as “imitations of real experiments”.

Findings of the reviewed comparative studies performed between 2005 and 2015 are however inconsistent, although there is an indication that student learning outcomes are achieved similarly or better in NTL than TL (Brinson, 20015). The deduction that there are no substantial differences between TL as opposed to NTL indicates that physical handling of apparatus is not always a requirement for understanding of concepts in constructivist-based teaching and learning. Zacharia, (2007:123) pointed out that the nature of learning and its outcomes do not substantially change when real experiment (RE) is substituted by virtual experiment (VE). It thus gives weight to the idea that VE can be used in some contexts to provide reliable laboratory experiences that are not substantially different from RE.

This brings us to Brinson's (2015) suggestion of “blended” or “hybrid” approach that incorporates both TL and NTL (virtual). This suggestion has been implemented in this study to enhance understanding of the basis of electromagnetism and to deal with persisting alternative conceptions. Not many research articles on such blending could be found. Zacharia and co-workers (e.g. Zacharia, 2007; Olympious & Zacharia, 2012; Zacharia & De Jong, 2014) investigated combination of TL (practical work) and NTL (computer simulations/virtuals) on electric circuits and waves (light and colour) and found out that it enhanced conceptual understanding and impacted positively in knowledge improvement.

The empirical study reported in this thesis gives focus on the topic of electromagnetism in physical sciences and investigates the use of relevant hands-on activities (TL) and computer simulations (NTL). Hands-on activities prescribed by the

physical sciences CAPS (2011) document were done together with selected simulations on aspects that learners often struggle to understand.

With regard to the teaching approach for conceptual development, modern research calls for a shift in thinking about science learning and teaching. Duschl, Maeng and Sezen (2011) reported on developments over the past century. Their review revealed a variety of perspectives regarding the design, validation and description of learning progressions and teaching sequences, a state that is probably “as it should be” (Duschl *et al.*, 2011:170). This study was carried out in the culture of didactics that focuses on subject content matter: how it is conceptualized in teaching and how the knowledge is constructed by learners (Klette, 2007). Design of teaching interventions in didactics emphasizes coherent understanding and transfer of content knowledge (Gilbert, Bulte & Pilot, 2011), learning demand and classroom communication (Amerttler, Leach & Scott, 2007) and the epistemology of the subject (Smith & Wiser, 2014). A core focus is choosing, ordering and sequencing concepts and activities (Duschl *et al.*, 2011:127).

Didactics research connects closely with the approach of conceptual change of learners’ intuitive ideas (Duschl *et al.* (2011: 128). Conceptual refinement of learners’ ideas based on everyday experiences is presently given preference above other approaches. The teaching sequence compiled and assessed in this study followed a conceptual refinement (or evolutionary) approach that Duschl *et al.* (2011) refer to as “work with it” instead of the more revolutionary “fix it” approach (p 134, 156, 158, 159, 173). This was done in the constructivist framework of learning.

1.2 THEORETICAL FRAMEWORK

1.2.1 Constructivism

This study was conducted in the constructivist learning theory, according to which learners build new knowledge from existing knowledge (Ausubel, 1968). Lemmer and du Toit (2010:40) indicated that the constructivist principle requires one to build knowledge starting with pre knowledge based on experiences. Conceptual understanding of these experiences, serves as foundation for new knowledge to be understood and formalized towards scientific concepts. A major challenge in physical sciences education is that learners' experiences tend to develop into alternative conceptions. Learners then go into class with several alternative conceptions as part of their existing knowledge. Since alternative conceptions differ from the accepted scientific concepts, they cannot serve as good foundation for the construction or development of the new and correct scientific knowledge and understanding. Alternative conceptions are basic mental schemas of how the learner observes and perceives the physical world in which they function (Redish, 2004:16). Teachers who hold the constructivist view of learning recognise that learners come with alternative conceptions that they have developed to explain the world around them. They are generally ideas that are reasonable and appropriate in a limited context, but further inappropriately applied in to situations where they do not work (Lemmer & du Toit, 2010:38). Therefore, teachers should select appropriate pre-conceptions and guide learners to develop them as scientifically acceptable conceptions.

Conceptual development can be hard to accomplish since it can be difficult to change existing or pre-conceived knowledge. To accomplish conceptual development towards correct scientific conceptions in a constructive way, learners' alternative conceptions need to be discredited to perceive the new concepts as believable, understandable and fruitful (Posner *et al.*, 1982). The study of Brinson (2015) and Zacharia (2007) offered evidence that non-traditional labs (NTL) and traditional labs (TL) were more or less the same in enabling the constructivist approach to teaching and learning of scientific concepts. Both strategies give emphasis to the importance of learners playing an active part in their own learning (Brinson, 2015:229) giving way for conceptual refinement (or concept refinement).

Conceptual refinement was adopted as a possible methods using practical work for constructive conceptual development in this study (Woolfolk, 2010:476).

1.2.2 Conceptual refinement

Conceptual refinement approach is a conceptual development method that builds up learners' experiential knowledge to physical sciences knowledge (Hammer, 2000; Redish, 2004). Elements of productive pre-conceived or existing knowledge are to be refined in a constructive way (Dekkers & Thjis, 1998). Lemmer & Lemmer (2010). The constructivist learning theory and the information processing model in a conceptual refinement didactical approach can be used to design teaching-learning sequences in physics. The conceptual refinement approach can subsequently be applied by a sequence of carefully selected activities to constructively develop scientific concepts and to bridge content knowledge gaps. Learners should be guided during the learning process to make sense of experiences and to build up concepts into a sound and consistent framework of knowledge (Scherr & Redish, 2005:41).

Based on the argumentation above, the teaching sequence that comprised of computer simulations (VE)/(NTL) and practical work (TL) (referred to as "blended" or "hybrid" approach to practical work) was implemented. The impact it will have on teachers for conceptual development in electrodynamics was then investigated, given that conceptual refinement approach was used.

1.3 AIMS AND OBJECTIVES OF THE STUDY

1.3.1 Aim

The aim of the study is to investigate the impact of a teaching sequence using practical work and simulations on physical sciences teachers' conceptual development of electrodynamics.

1.3.2 Objectives

In order to respond to the aim of the study, the following objectives were designed:

1. To determine the challenges that physical sciences teachers experience regarding electrodynamics and underlying concepts
2. To design a teaching sequence comprising of practical work and computer simulations activities in order to enhance conceptual understanding of electrodynamics among physical sciences teachers.
3. To investigate the impact of the designed teaching sequence for the conceptual development and improvement of teachers' knowledge of electrodynamics among the physical sciences teachers.
4. To derive subject-related learning principles for conceptual development and make recommendations concerning implementation of these principles in teaching sequence for learning gain.

1.3.3 Research questions

1.3.3.1 *Main research question*

What is the impact of a teaching sequence using practical work and simulations on physical sciences teachers' conceptual development in electrodynamics?

1.3.3.2 *Secondary research questions*

In order to achieve the above-mentioned research question, the following secondary questions were addressed:

1. What challenges do physical sciences teachers experience with regard to electrodynamics and what are the underlying concepts?
2. What teaching sequence comprising of hybrid practical work for conceptual development of electrodynamics can be designed?
3. What impact will the designed teaching sequence have on the conceptual development and improvement of knowledge of electrodynamics among the physical sciences teachers?

4. How can the derived subject-related learning principles for conceptual development be implemented in the teaching sequence for learning gain?

1.4 RESEARCH DESIGN, METHODOLOGY AND METHODS

1.4.1 Literature review

The literature review of this study was in such a way that it presents the existing challenges on the teaching and learning of Electrodynamics in Further Education and training (FET) schools, with more focus on the ways it can be presented with understanding. Relevant literature sources at the NWU libraries and electronic sources through the internet, academic books, journals and articles related to the study were obtained with the aid of search engines such as EBSCO Host and Google Scholar.

The literature review was used to direct the development of a questionnaire to probe in participants' pre-conceive content knowledge related to electrodynamics concepts. Figure 1.1 below gave a summary of chapters of the literature review that contributed to the empirical study of this research. The literature reviewed key concepts in electrodynamics; the learning of electrodynamics; and the teaching of electrodynamics. The literature study in Chapter 2 reviewed the relevant content knowledge on electromagnetism with regard to the historic development of the topic and the prescribed CAPS syllabus. Chapter 3 reviewed problem areas or challenges in the learning of electrodynamics to give an idea on difficult concepts that might need attention in this study. Chapter 4 dealt with instructional models, approaches and strategies for conceptual development. Chapter 5 then put the research design and methodology relevant for the empirical research into perspective. The diagram below depicts the input of the literature reviews to the design and methods of this study.

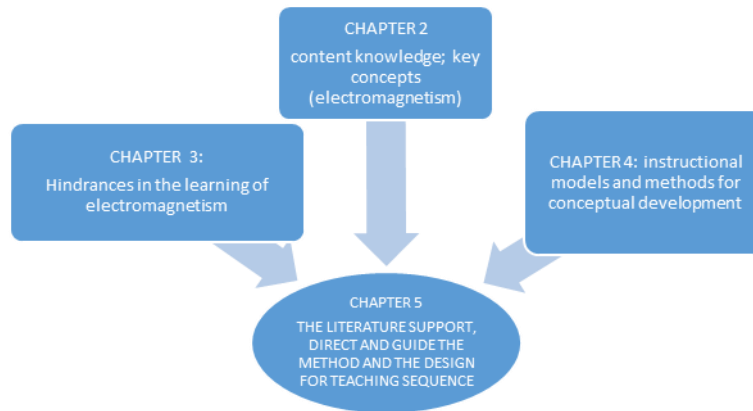


Figure 1.1: Literature review overview

1.4.2 Research design

A **‘pre-test-post-test control-group** design involving an experimental and control group was undergone in this study (Creswell, 2009:228). The same questionnaire (pre-test and a post-test) were administered in both groups. The same conceptual development model with the same content knowledge and presentation of concepts was also applied to both experimental and control group. The only difference was that the teaching strategy for the experimental group infused the use of hybrid practical work in the teaching sequence for conceptual development while the control group presentation followed the traditional teaching approach only.

1.4.3 Embedded mixed research method

Embedded mixed methods research was used in this study, which involved the mixing of qualitative and quantitative approaches. Mixed methods research is defined by Creswell and Plano (2007) and Creswell (2009:4) as *“an approach to inquiry that combines or associates both qualitative and quantitative forms”*. In this study, the quantitative (quan) data was embedded within a qualitative (QUAL) experimental design. The reason for choosing this approach was to mainly enhance qualitative study with a supplemental quantitative data set. Embedded mixed method was used to answer secondary research questions that are related to the main research question of this study. The quantitative survey data was collected to help describe the broader context of the qualitative case study. The two types of data

collection were intended to supplement each other for a broad analysis and interpretation of results (Creswell, 2009:10-11; Maree, 2012:275-276).

Collection of data occurred in three phases for both groups (before, during and after the intervention). QUAL data was collected more than quan data, meaning more priority was given to qualitative data collection (Creswell, 2009:205; Creswell, 211). Quan-QUAL data collection took place before and after the intervention and during intervention only QUAL data was collected. The quan was collected using closed question type and QUAL in the form of open ended question type and discussions that were video recorded. The illustration in Figure 1.2 below describes the embedded mixed method design that was adopted in this study.

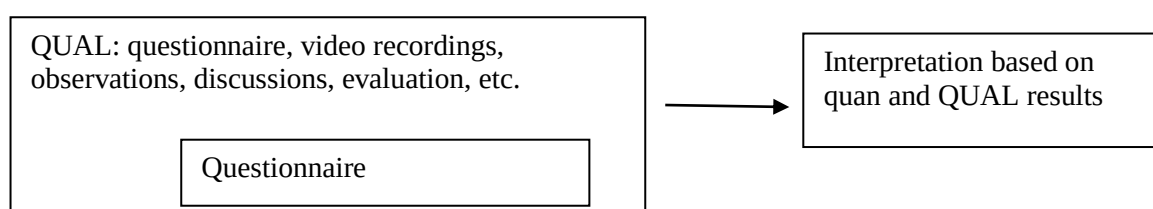


Figure 1.2: Embedded mixed method design procedure (Maree, 2012:281)

1.4.3.1 *The first phase: pre-knowledge and challenges of participants (objective 1)*

In the first phase of the empirical study the Quan-QUAL data was collected concurrently in this phase to determine the participants' existing knowledge and challenges they experience in the teaching and learning of electrodynamics (Objective 1). The intent of the quan data, in the form of a pre-test, was to explore and probe into participants' content knowledge to determine the knowledge gaps, alternative conceptions, confusions, difficulties and any other challenges that are a hindrance to the understanding of electrodynamics. QUAL data was collected by means of a pre-test (open ended questionnaire) and participants' reflective written reports supported by discussions that were lead and facilitated by the researcher and video recorded. The results of the first phase informed the researcher about the important observations and point or concepts to focus on during the intervention.

1.4.3.2 *The second phase: intervention (objective 2 and 3)*

The purpose of the intervention was to meaningfully engage the participants so that they are self-sufficient in the teaching of electrodynamics in the FET syllabus. The intention was to reconstruct the participants' pre-conceived knowledge, to capacitate them with correct and sufficient scientific knowledge of electrodynamics to teach the topic. During the intervention, the participants learned the FET syllabus content (electrodynamics) and the teaching sequence for the intervention enforced conceptual refinement approaches using practical demonstrations and computer simulations. While the experiments were demonstrated and observed by the experimental group, questions were asked to direct conceptually develop of their knowledge in electrodynamics and to improve their understanding. The same teaching sequence having the same concepts in the same order were administered in the two groups (experimental and control) to address conceptual problems and difficulties encountered before and during the intervention. The main difference between the teaching sequences was that simulations and practical work were merged in the experimental teaching sequence only, while the control group performed no activities. Since the control group also need to be capacitated for correct implementation in the teaching of the topic, the researcher intended to expose these activities that were presented for the experimental group to the control group as well, particularly all the simulations after post data collection.

Figure 1.3 below gives a summary of the model that was used in the development of the experimental teaching sequence in order to achieve the aims and objectives of this research. The conceptual development model for conceptual refinement was applied with the aid of computer simulations and practical demonstrations (hybrid practical work).

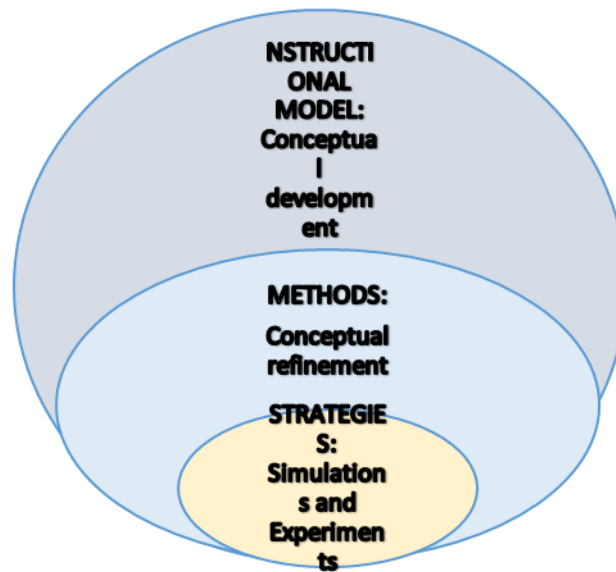


Figure 1.3: Conceptual development instruction (Adapted from Gunter *et al.*, 2007:34)

1.4.3.3 *The third phase: The impact of intervention (objectives 3)*

Quan-QUAL data was collected concurrently after the intervention to interpret the impact of the methods used in the two groups and for comparison. The same questionnaire that was used as the pre-test was also administered as a post-test to establish the participants' learning gain of the content knowledge. Qualitative methods were utilised to gain a better understanding of the participants' conceptual development and experiences during the teaching sequence and the impact that the simulations and practical work had on knowledge improvement. QUAL data was collected using open ended questionnaire, an evaluation form and video recorded group discussions in this phase.

At the end of the three phases, the results of all data were interpreted and discussed to deduce the impact of the intervention.

1.4.4 The researcher's role

The researcher designed a teaching sequence and evaluated its effectiveness during the empirical investigation. Research instruments to collect quantitative and qualitative data were self-compiled. A three-day content workshop was conducted by the researcher. This gave the researcher an opportunity to identify and reconstruct the participants' insufficient knowledge while collecting the qualitative data. The data that was collected during the empirical study was interpreted and analysed to determine the impact of the teaching sequence used in this study.

1.4.5 The study population

The study was conducted in the South African context in the North West Province. The North West Province is made up of four education districts and each district consists of circuits. Kgetleng circuit in Ngaka Modiri Molema district was sampled for this study. The circuit consisted of two clusters and the researcher was the employee of Ngaka Modiri Molema district where the clusters are attached. The schools were based in deep rural areas and teachers in those schools experienced similar contextual factors. Similarity of contextual factors was based on profiling of schools according to the Province/district, referred to as Village, Small Dorpie, Township (VSDT) category, and both were quintile 1(no fee) schools. The circuits whose teachers formed the experimental group were not different from the control group; hence the selection was random and qualified any group to be the experimental group. Physical sciences teachers from these clusters participated in the empirical study. Elands cluster consisted of (16) FET school and Madikwe cluster consisted of fifteen (15) schools. In most rural areas, there was only one physical sciences teacher per school, so the anticipated numbers were 15-17 participants per group. The procedure was the same for both groups, except for the intervention strategies that was used in the two groups. Participants were selected purposefully for relevance and to enable the researcher to best understand the research problem.

1.4.6 The research site

The researcher sampled physical sciences teachers of the two clusters as mentioned in paragraph 1.4.5 above. Both groups were to use the same venue but on different dates. The research was conducted at the circuit office and the hall was used as venue.

1.4.7 Quantitative part of the research

The quantitative part of this study was conducted by means of an experimental method plan which, according to Creswell (2009), is used to test the impact of intervention on an outcome whilst the researcher controls all other factors that might influence the outcome. This is also supported by Meltzer (1998:1261) who is of the opinion that, to assess learning, it is necessary to have a measure that reflects the transition between knowledge at different states and that has maximum dependence on instruction, with minimum dependence on learners' pre-instruction states. Such a measure is provided by calculation of average normalised learning gains from the pre- and post-test results as indicator of the effectiveness of an intervention (Hake, 1998; Meltzer, 2002:1259-1264).

The intention for quan data collection in this study was to compare the content learning gained during the experiment and control interventions (Creswell, 2009:115, 208, 229). It should give a valid indication of the impact of teaching sequences (Hake, 1998:1) - the interactive method in comparison to the traditional method in this case.

1.4.7.1 *Data collection and measuring instrument*

Data was collected quantitatively by means of a questionnaire, where the pre- and post-test were used for the understanding of acquired knowledge gained during the intervention. The questionnaire was used as a pre-test during the first phase of the research to check the participants' pre-knowledge and content gaps and then again as a post-test (third phase) to check knowledge improvement after intervention. Three-day workshops for data collection and intervention were allocated for both groups. The pre-tests were written before the workshops and the post-test at the end

of the workshops. A period of two weeks was anticipated between pre- and post-tests.

The questionnaire was compiled and extracted from different materials related to the FET syllabus as informed by CAPS, the internet, academic books, recent journals, articles and also from previous Grade 12 examination papers for physics. Physical sciences teachers were expected to answer these questions as they were involved in the teaching of this syllabus on a daily basis.

1.4.7.2 *Reliability and validity*

Reliability indicates consistency of the scores in a test, while validity indicates the appropriateness of a test. They are both important for judging the suitability of measuring instruments (Gay & Airasian, 2003:141). Reliability is the level to which a questionnaire consistently measures what it intends to measure (Creswell, 2009:233). Consistency in this study referred to the use of the same questionnaire for both groups and the learning of the same concepts over the same period, in order to be able to measure the impact interventions had on knowledge improvement.

Validity refers to whether meaningful and useful conclusions could be drawn from scores on instruments (Creswell, 2009:235). In this study, each group wrote the same test twice. For content validity, the questionnaire was given to three experts in physical sciences education research. These three experts were each given the structured questionnaire to read, answer and to make valuable suggestions for validity purposes. A cohort of 50 in-service teachers who registered in the North-West University for the Advanced Certificate in Education for physical sciences was given the questionnaire to respond to items. The permission was granted by the North-West University Faculty of Education. The questionnaire was therefore subjected to a pilot study ensure validity, quality assurance and standardisation of it, and the necessary changes were made before the empirical study. A statistical consultant at the North-West University reviewed the questionnaire for its validity and reliability.

1.4.7.3 *Data analysis*

Creswell (2009:11) indicated that a pre-test and post-test method provide a valid measurement of the impact of an intervention. Since the number of participants in this study was small, average normalised learning gains were calculated per item from the results of the pre- and post-tests to compare the effectiveness of the interventions with the experimental and control groups. Average normalised learning gains take into account the differences in the pre-test scores of the two groups (Hake, 1998).

1.4.8 Qualitative part of the research

According to Locke *et al.* (1987), as cited by Creswell (2009:194), the purpose of qualitative research is to understand a specific social situation, role, group, event or interaction. This type of research does not use one source, but multiple data sources (Creswell, 2009:175). Participants' written reports, video-recorded interventions and discussions complemented each other in this study and were analysed afterwards. The research approach assisted to probe deeper in the participants' experiences, difficulties and conceptual development. The qualitative data was interpreted to obtain a deeper understanding of the results.

1.4.8.1 *Data collection strategies*

For the purpose of this study, QUAL data was collected by means of video records, as well as participants' written reports (reflections and evaluation reports). In the first phase, the participants were asked to reflect (in writing) on concepts that they thought were difficult in electromagnetism and to give reasons as to why they thought so. This was followed by group discussions based on their written reflections were they were reading them out for discussions, and were video recorded. During the intervention (second phase), the developed teaching sequence was implemented in a three-day workshop and was video recorded. After the intervention (third phase), all participants were asked to evaluate, in writing, the impact of how the strategies sufficiently addressed their problems. They also reflected on the advantages and limitations of the intervention and the strategies used. Then they were asked to

explain and clarify their individual written reports in group discussions and were also video recorded.

1.4.8.2 *Trustworthiness*

A knowledgeable colleague on the research content area and qualitative research was asked to examine the data and to provide evidence for themes. Disconfirming evidence contrary to the established evidence was to be reported by the researcher where applicable (Creswell & Plano Clark, 2007:135).

1.4.8.3 *Data analysis*

Video recordings were to be transcribed and organised categorically, reviewed repeatedly and coded continually (Creswell, 2009:199). Participants' written reports were intended to be coded and compared with data obtained from the video recordings.

1.5 ETHICAL ASPECTS OF THE RESEARCH

Permission to conduct research was requested from the North West Department of Basic Education as well as from the principals of the selected schools. The researcher informed the participants about the nature and purpose of the research, as well as the ethical considerations that guided the research. Respondents were informed about all data collection methods and activities and how data was utilised. The participants were informed that participation was voluntary and that they might withdraw at any time, without penalisation. The confidentiality of information conveyed by participants during the quantitative and qualitative data and reports was ensured. The intention of the research was not to harm the respondents since they were expected to gain from the study. For the benefit of the control group, the researcher replayed the simulations (non-traditional laboratory / virtual experiments) that were presented / projected for the experimental group. The simulations were replayed after the control group wrote the post-test. The Ethical issues as per committee for the North-West University were observed for this research project.

1.6 CONTRIBUTIONS TO THE STUDY

The study hoped to contribute to physics education research by opening new possibilities for improving physical sciences teaching and learning achievements, specifically in the teaching of electrodynamics in FET schools. The aim was further to provide information that can be used to recommend changes to the existing instructional approaches that have not been impacting the teaching and learning of physical sciences positively. The research intended to uplift the standard of physical sciences teaching by recommending infusion of interactive methods in conventional teaching as strategies for proper content learning and teaching. The intention of the research was furthermore to reconstruct and bridge participants' knowledge gaps and to improve knowledge during the intervention. Since few, if any, research has been done on the conceptual development of electrodynamics and also on the combination of practical demonstration and simulation in physical sciences education, the research was to contribute internationally to the research in the physical Sciences education field.

1.7 KEY WORDS AND CLARIFICATION

1.7.1 Teaching sequence

According to Gunter *et al.* (2007:34) a teaching sequence refers to the order in which subject matter is placed. For instance, the content of subjects is usually sequenced from known to unknown and the easy to the more abstract. The sequence of learning must follow a logical order and noticeable and understandable connections needed to be embraced in what must be learned and what was known before by learners. According to Staver (2007:23), teachers need to integrate the core scientific knowledge and scientific inquiry to expand and to contextualise science and its applications.

1.7.2 Conceptual development

Conceptual development is a progression knowledge concept where the existing concepts harmoniously fit into learners' existing mental representations (Redish, 1994:11). A new concept that is learned should be described or explained using pre-

concepts learned in everyday life context so that learning could be effective. Everyday life situations could be the first step to build learners' new and abstract mental structures and content knowledge (Lemmer, 2013). To allow effective conceptual development, learners should recognise and comprehend appropriate concepts and place them into their conceptual framework, so that knowledge is well comprehended and correctly applied. Chapters 2 and 4 present detailed review on conceptual development.

1.7.3 Computer PhET simulations

PHET simulations are a programme that creates and provide helpful and practical animations and simulations for teaching and learning of practical subjects such as physical sciences. It is a communication media that is directed and coordinated by the computer and depicted on the screen (Jenkinson & Fraiman, 1999:283). Trey and Khan (2008) highlighted the application of PHET simulations where processes and phenomena could not be practical, observed and explored in the real world. The activities in the program assist the learners to visualise concepts that are abstract and complex. The program could be played repeatedly and the learner controls his/her own pace of learning. The program contributes to the diversification of the lessons and learners get instant feedback and important pointers during the lessons (Stavy, 2007:54). In this study, relevant PhET and U-tube simulations were to be used to simulate traditional laboratory (TL) or present virtual experiments (VE), in order to achieve the objectives of this study.

1.7.4 Practical work

Mhlongo (2010) defines practical work as: *"a set of instructions followed to verify a certain concept or law"*. Practical work plays an important role in physical sciences education and scientific theories could be learned through it (Koponen & Mäntylä, 2006:31). The intention of practical work in physical sciences communities includes certain inquiry skills such as observations, measurements, data collections and analysis of results. The physical sciences CAPS (2011:144) policy document focus the attention of practical work to the process skills required for scientific inquiry and problem solving. The policy emphasises that learners be assessed on their use of scientific inquiry skills, such as planning, observing and gathering information,

comprehending, synthesising, generalising and communicating results and conclusions. The improvement of the understanding of theoretical work to make the processes and phenomena real could be achieved through observations and experiences (Koponen & Mäntylä, 2006). Through practical work, learners may learn to be efficient, self-reliant, analytical, observe, manipulate, measure, reason, and to learn on their own. Practical work or Traditional Laboratory includes individual laboratory experiments and practical demonstrations and both add value to learners' science education (Bybee, Powell & Trowbridge, 2008:235). According to Ramnarain and Kiribige (2010:3-4) practical work can be classified as teacher demonstration or learners' independent practical activities. This study adopted a teacher demonstration approach, which involved learners watching the teacher illustrating and generating data while observing. The demonstration was mainly content based.

1.7.5 Electrodynamics

The part of electrodynamics prescribed in the Further Education and Training (FET) phase progresses from basic knowledge of electricity and magnetism, through concepts of electromagnetism and electromagnetic induction, to generators, electric motors and transformers referred to as applications (DBE, 2011:143-149; DoE, 2006:94-95). "Electrodynamics is the study of electric charges in motion; the forces created by electric and magnetic fields and the relationship between them" (Oxford dictionary of p, 2000:138). Electrodynamics is the research topic of this study and the core knowledge of this topic is electromagnetism and electromagnetic induction.

CHAPTER 2: CONCEPTUAL DEVELOPMENT IN ELECTRODYNAMICS

2.1 INTRODUCTION

Electrodynamics is the “study of electric charges that are moving due to forces produced by magnetic and electric fields and the relationship between them” (Oxford dictionary of physics, 2000:138). Prescott (2006) defines electrodynamics as the “combination of the magnetic field and the electric field as they interact to produce a force”. The impact that improvement of knowledge of electrodynamics has on life of mankind cannot be underestimated. Hair clippers, hairdryers, electric fans, blenders and electric bells are electrical devices commonly used today and are applications of electrodynamics. The operations of these electrical devices apply the theory of electrodynamics. These devices are examples of basic applications of everyday real life situations that teachers must relate to classroom physics content thereby making physics real, simple and exciting (White, 1988:46). The rationale in this study was to present an orderly electrodynamics concepts and include practices that are critical for development of scientific knowledge and reasoning, thereby developing a teaching sequence that require instructional support and mediation via sound curriculum and practical strategies. A school curriculum provides guidance of how concepts should unfold and constructively progress in order to reach objectives for knowledge progression. Klette (2007:147) described knowledge progression as a relation between teachers and learners, as well as subject matter and instructional methods. Research of learning progressions (such as teaching sequences) have been identified as possible and plausible means to reform and redesign curricula and align them to instruction and assessment (Duschl *et al.*, 124 – 125, 166).

This chapter mainly reviewed the conceptual development and structure of content in electrodynamics. Furthermore, it reviewed the historical development of concepts in electrodynamics; (section 2.2) followed by the development of concepts as outlined in the FET syllabus or curriculum (section 2.3). The last section (2.4) discussed practical work as prescribed in the FET syllabus.

The three sections on electrodynamics presented in this chapter (i.e. the historical development, prescribed FET curriculum and requirements for practical work) serve

as a guideline for organising the electrodynamics concepts for conceptual development in this study. The next paragraph discusses the history of the development of concepts towards electrodynamics.

2.2 HISTORICAL DEVELOPMENT OF ELECTRODYNAMICS

2.2.1 Discoveries and inventions for concept developments of electrodynamics

The profound influence that the discovery of electromagnetism has in the development of technology that came to be applied by man is evident even today. It is true and avoidant in our society where all modern inventions such as power plants, satellite communications, etc., are the results of our improved knowledge and understanding of discoveries in the ancient history (Urban, 2000:34). The next paragraphs give summaries of discoveries and development of concepts progression related to electrodynamics.

William Gilbert did investigations about magnets, magnetic materials as well as the earth as giant magnet (1660). He noted the different character of electrical and magnetic forces and presented models of electricity and magnetism. Furthermore, he described the method of synthetically magnetising iron. Gilbert's (1660) ideas of magnetic force lead him to investigate its increase with the magnitude or quantity of lodestone and the attraction between magnets and objects made of iron. To aid navigation, William performed experiments and constructed physical models to show how the direction of the magnetic compass (and thus the magnetic field) varies with respect to position on the earth (Nave, 2011:1).

Until 1815 there had been a growing awareness that electricity and magnetism are closely related, but the belief could not be verified experimentally. In that year, Jean Hans Christian Oersted, a Danish physicist and chemist, happened to conduct current electricity through a wire next to a compass. As the current started flowing, the needle was deflected and remained in that position until the current was switched off. Nave (2011:3) stated that Hans Christian Ørsted was convinced that magnetic fields were produced around a wire with life current and he established the direct relationship between electricity and magnetism. Oersted conducted his first

experiments to connect electricity and magnetism in 1820. He noticed that a compass needle deflects in opposite directions when the electric current was switched on and off. The motion of a compass-needle also changed with a change in the direction of current flow. The experiments convinced him that magnetic fields orbit around moving charges. After repeated investigations, he published the results of his experiments that revealed the existence of a magnetic field around an electric current in a wire. By proving that an electric current produces a magnetic field around it, Oersted established and confirmed the connection between electricity and magnetism. The diagram below illustrates Oersted discovery.



Figure 2.1: Magnetic field around a charge

Following Oersted findings, during the same year of **1820**, Johann Salomo Christoph Schweigger (German chemist), built the first sensitive **galvanometer (measuring instrument)**. He invented it by wrapping a conducting wire (coil) around a compass with equally spaced marks on it and it was accepted as an instrument for measuring and detecting small electric currents. The magnetic forces on a loop are proportional to the electric current flowing in the particular length of the conductor and the magnetic field crossing that conductor. This fact makes the torque on a current-carrying loop or coil useful for measuring electric current. Most simple electric meters have a coil of wire with a needle attached to it. A permanent magnet provides the magnetic field and a spring returns the needle to the zero point, refer to Figure 2.2 below (Griffith, 1992:273).

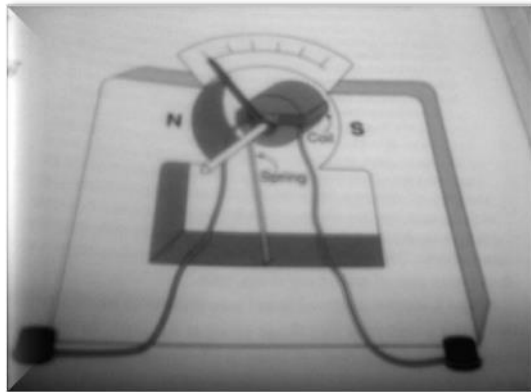


Figure 2.2: An electric meter (Griffith, 1992:273)

Nave (2011:2) stated another contribution of electromagnetism made by Andre Marie Ampere in 1820. Ampere conducted experiments trying to establish a joint, collective theory of electricity and magnetism after Oersted's discovery. He thought that if a current carrying conductor produced a magnetic field around it, then the magnetic fields of two conducting wires would interact. The experiment was conducted and the interaction was considered to be simple and fundamental. From the results obtained from the experiment, he then concluded that if currents flow in the same direction in parallel conductors the wires would be attracted towards each other, while repulsion would occur for opposing currents. He further derived **Ampère's law**, a mathematical expression for the magnetic force between two electric currents. Accordingly, the force between two long parallel currents is directly proportional to the strength of the current in each and inversely proportional to the distance between the conductors.

In **1825** William Sturgeon invented the **electromagnet**. He wound several turns of coil around a piece of iron. The core is only magnetised while an electric current is flowing through the coil and his invention was called the electromagnet. Sturgeon used an iron core in the form of a horse-shoe shape to bring the poles nearer each other, consequently intensifying the magnetic field. He further found that the effectiveness of the electromagnetic was increased when a ferromagnetic core (like iron) is used and a large current is provided by a battery. The ferromagnetic properties allow the magnetic domains inside the iron core to align due to the magnetic field of the current carrying solenoid. (Nave, 2011:3). The magnetic field

produced by electric current in a solenoid coil is the same as that of a bar magnet, see Figure 2.3 below. Sturgeon was the first person to construct a magnet that could raise a mass of nine pounds. His discovery also formed the basis of using electrical energy for electronic communications.

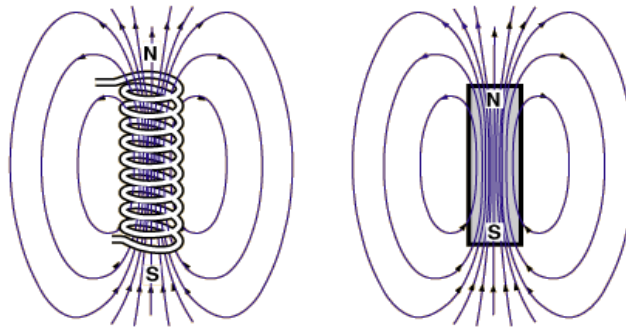


Figure 2.3: electric field around a solenoid and a bar magnet (Nave, 2011:3)

Oersted's discovery of the connection between electricity (E) and magnetic field (B) was a complete surprise and stimulated many further experiments to probe the connection between electricity and magnetism. Ten years after his discovery that electric current produces a magnetic field; the reverse was discovered by Francesco Zantedeschi. It was highlighted that the two fields were not the same, but related in a most discrete and intimate way. In 1830 Zantedeschi revealed that electric current is produced in closed circuits by a magnet going in and out of a coil. The important aspect that was emphasised about the connection between electricity and magnetism was that a changing magnetic field can create an electrical field and a changing electrical field can create a magnetic field (Nave, 2011:1). This preceded the discovery of electromagnetic induction by Michael Faraday, who is usually given credit for it.

Faraday began his sequence of experiments in 1831 that resulted in his mathematical formulation of the law of electromagnetic induction. He discovered that a changing magnetic field creates an electric field. He found that a magnetic field of a bar magnet penetrating a coil induces current in the loop when that bar magnet is in motion. He described the occurrence as Faraday's law of induction. According to Faraday's law; "the EMF induced along a closed path such as wire loop depends on changes in the magnetic flux through the area enclosed by that path". The following

were found to be the factor affecting the induced EMF (ϵ): The rate of change in magnetic flux $-\Delta\phi/\Delta t$. The magnitude of EMF (ϵ) is directly proportional to change of flux ($\Delta\phi$) and inversely proportional to the rate (Δt) at which it changes. If the magnetic flux is not changing, then no EMF (ϵ) will be induced (Giordano, 2013:717).

Modern electrodynamics was founded on Faradays' experiments and discoveries. The electric motor is considered to be one of Faraday's major inventions in electromagnetism. He also invented the first electric generator. He could easily design it by changing the velocity of the flux (ϕ) to produce any desired voltage and making use of stronger magnets. This followed from his finding that if one moves a magnet through a closed wire, an electric current is produced in the wire. Faraday also contributed to modern electromagnetism by his introduction of the concepts of magnetic field lines and flux that is still used today to visualise magnetic and electric fields. These models aided in generalising the field theory. Faraday was rewarded for his contributions by the Farad being the unit of magnetic induction and Faraday's law that was named after him. (Williams, 2015:1-4).

In **1832** Joseph Henry independently made the same discovery about electromagnetic induction as Faraday the year before. He also revealed the phenomena of self-induction and mutual induction. In an experiment, he induced a current in a wire that was two storeys below an identical current-carrying wire. In **1835** Henry additionally came up with the idea to insulate wires, which allowed him to make a strong electromagnet by densely winding insulated wire around an iron core. Consequently, he was the first to construct a magnet that could lift a load weighing 3500 pounds, thereby improving on William Sturgeon's electromagnet. Furthermore, Joseph Henry invented the electric relay which is an electrical switch (Williams, 2015:1-4).

In **1833**, Heinrich Lenz expanded on the work of Faraday that brought along **Lenz's law** that states Giordano (2013:717): "If the changing magnetic flux induces a voltage in a closed circuit, then the consequential current will also produce an opposing magnetic flux". Lenz added that "an induced current in a closed circuit will emerge in such a direction that will be in opposition to the change that produced it". Lenz's law is an outcome of the principle of conservation of energy. If current is induced in a coil due to the change in magnetic flux, it will be such that it opposes

the change that caused it. Lenz's law follows from the negative sign in the equation of Faraday's law of induction. The symbol L , conventionally representing inductance and its SI unit Henry (H), was chosen to honour Heinrich Lenz.

In **1865** James Clerk Maxwell introduced the concept of electromagnetic field that unified electric and magnetic fields. He showed that electromagnetic fields (i.e. the combination of **electric and magnetic fields**) propagate through space as waves. In vacuum, electromagnetic waves travel at a constant velocity of about 3.0×10^8 m/s. Maxwell's thesis on electricity and magnetism was published in 1873. He summarised and systemised the work of his predecessors (Coulomb, Oersted, Ampere and Faraday) and expressed the results mathematically in the four equations named after him (i.e. the Maxwell equations) (Williams, 2015:1-4).

From the historical development described above, follows that the theory of electromagnetism and electrodynamics as we know it today, resulted from the joined effort of several 19th century scientists, their experimental innovations and critical, analytical thinking. Their work founded the contemporary electromagnetic theory as well as electrodynamics and its applications such as the electric motor and the generator. These efforts and contributions are still evident today and a few of the modern developments are discussed in the next paragraph.

2.2.2 Modern applications of electrodynamics

Magnetic fields have several uses and various functions back from the olden days and even nowadays in recent times. This section gives a brief summary of the modern view or the latest applications of electrodynamics ever since the discoveries and inventions of the scientists from the olden days (Cornwall, 2000:217).

One of the recent developments in electrodynamics is the applications of the earth's magnetic field utilised in technology for navigation. The earth's magnetic field makes life easy today by providing directions to the desired destiny. It is applied in navigation since the north pole of a compass gives direction by pointing to the south pole of Earth's magnetic field. The magnetic south pole of the earth is referred to as the Geographic North or the true North of the earth. Other applications of magnetic fields are found in electric motors and generators (Wikipedia, 2013:48).

In the application of generation of electricity in the power station, an electric generator is described as a machine that converts mechanical energy to electrical energy. The device generates current electricity to flow in the external circuit. The steam engine drives the turbines to provide movement as a source of mechanical energy. Different sources of mechanical energy includes a wind turbine, water falling through a waterwheel or turbine, a hand crank, compressed air, an internal combustion engine. Generators supply almost every electric power grid in power stations (Kuphaldt, 2006:1-48).

Another recent application is found in bicycle odometers, like those found in the sport centres and gymnasiums. These modern applications also apply Faraday's law to work out and compute the number of rotation or cycles of a bicycle wheel. A tiny permanent magnet is mounted to a spoke and a pickup coil is attached on the frame of the wheel. When the changing magnetic flux occurs as it crosses the pickup coil, the voltage is induced in the coil. The pickup coil is linked to a computer that keeps track of the number of pulses in the induced voltage signal and also measures the time between pulses. The information is then shown as the velocity and displacement of the bicycle in the display window (Giordano 2013:735).

Electric motors are another electrodynamics application. Motors function through the interaction of magnetic field and electric currents to produce a force within the motor. The modern applications of motors include tiny motors in electric watches and in electric meters like voltmeters, ammeters, etc. Different types of motors with remarkably standardised sizes and quality features offer suitable, convenient and proper mechanical power for the industries (Griffith, 1992:273). Kinds of electric motors can be classified by its electric power supply, internal construction, application, output, etc. To cite some of the examples of applications of the largest electric motors in the industries, they are used as driving force for ships to give them a starting power, compressions to gain momentum and pumped-storage.

2.2.3 Timeline of important events in historical development

The following table (Table 2.1) represents and summarises the timeline of important historical development of concepts in electrodynamics.

Table 2.1: Timeline of important events in the historical development of electrodynamics

YEAR	SCIENTIST:	EVENT/DISCOVERY/INVENTION
1550	Girolamo Cardano	Identified differences between magnetic and electrical forces
1600	William Gilbert	Magnetised iron synthetically Constructed a physical model of the Earth's magnetic field
1815	Jean Hans Christian Oersted	Deduced the close relationship existing between electricity and magnetism from an observation.
1820	Jean Hans Christian Oersted	Revealed experimentally that an electric current flowing in a conductor produces a magnetic field around the conductor.
1820	Johann Salomo Christoph Schweigger	Built the first sensitive galvanometer (measuring instrument of small currents)
1820	Andre Marie Ampere	Revealed that parallel conductors attract each other if the currents are in the same direction, while they repel when the currents are in opposite directions. This phenomenon is used to define the Ampere as unit of electric current.
1825	William Sturgeon	Invented the first electromagnet.
1830	Francesco Zantedeschi	Discovered that electric currents are induced in a coil by pushing the magnet in and out of the coil, thus preceded the discovery of electromagnetic induction attributed to Michael Faraday
1831	Michael Faraday	Introduced the concepts of fields and flux. Formulated the law of electromagnetic induction and invented the electric motor.
1832	Joseph Henry	Independently discovered electromagnetic induction, including self- and mutual induction. Invented the electric relay, an electrical switch
1833	Heinrich Friedrich Emil Lenz	Formulated Lenz's law in electrodynamics.
1835	Joseph Henry	Increased the strength of electromagnets by using insulated wires.
1865	James Clerk Maxwell	Introduced the concept of electromagnetic field as a combination of electric and magnetic fields.

1873	James Clerk Maxwell	Published a thesis on “Electricity and Magnetism” with Maxwell’s four equations that synthesize the findings of Coulomb, Oersted, Ampere, Faraday and other 19 th century scientists on electromagnetism.
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This section covered a conceptual domain of historical development of electrodynamics. The next paragraphs discuss the conceptual development of electrodynamics in the FET syllabus as stated in the CAPS document.

2.3 CONCEPTUAL DEVELOPMENT IN THE FET SYLLABUS

2.3.1 CAPS syllabus on electrodynamics

Electrodynamics is one the topics in FET syllabus coverage that are examined in the Grade 12 final school examination. Electrodynamics in the Further Education and Training (FET) phase, progresses from basic knowledge of electricity and magnetism, through to electromagnetic induction, towards the applications thereof in generators and motors (DBE, 2011:143-149; DoE, 2006:94-95). Table 2.2 is copied from the CAPS document (physical sciences CAPS, 2011) and gives an overview of electrodynamics syllabus in the FET band (i.e. from Grade 10 to 12). It can be referred to in page 19 for grade 10, page 86-88 for grade 11 and page 130-131 for grade 12. The details of content and concepts to be covered in the syllabus are noted in column three of the table.

Table 2.2: Physical sciences FET syllabus coverage. (physical sciences CAPS, 2011)

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
0.25 hours	Magnetic and nonmagnetic materials.	• Revise how to test and classify materials as magnetic and non-magnetic • Give examples of materials that are magnetic and nonmagnetic • Give examples of the use we make of magnets in daily life (in speakers, in telephones, electric motors, as compasses)	• Test the following Substance to classify them as magnetic, or nonmagnetic: glass, wood, graphite, copper, zinc, aluminium, iron nail and materials of your own choice		
Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
6 HRS	Electromagnetism				
	Magnetic field	• Provide evidence for the	Practical	Materials:	A simple form of evidence

3 hours	associated with current carrying wires	existence of a magnetic field (B) near a current carrying wire • Use the Right Hand Rule to determine the magnetic field (B) associated with: (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Draw the magnetic field lines around (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Discuss qualitatively the environmental impact of overhead electrical cables	Demonstration: Get learners to observe the magnetic field around a current carrying wire Project: Make an electromagnet	Power supply, wire, retort stand, cardboard, several compasses. Iron nail, thin insulated copper wire, two or more D-cell batteries, one pair of wire stripper, paper clips.	for the existence of a magnetic field near a current carrying wire is that a compass needle placed near the wire will deflect
3 hours	Faraday's Law.	• State Faraday's Law. • Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer • Use the Right Hand Rule to determine the direction of the induced current in a solenoid when the north or south pole of a magnet is inserted or pulled out • Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (Φ) passing through the loop is defined as: $\Phi = BA \cos \theta$, where θ is the angle between the magnetic field B and the normal to the loop of area A • Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux • Calculate the induced emf and induced current for situations involving a changing magnetic field using the equation for Faraday's Law: where $\Phi = BA \cos \theta$ is the magnetic flux	Practical Demonstration: Faraday's law	Materials: Solenoid, bar magnet, galvanometer, connecting wires.	Stress that Faraday's Law relates induced EMF to the rate of change of flux, which is the product of the magnetic field and the cross-sectional area the field lines pass through. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change. The directions of currents and associated magnetic fields can all be found using only the Right Hand Rule. When the fingers of the right hand are pointed in the direction of the current, the thumb points in the direction of the magnetic field. When the thumb is pointed in the direction of the magnetic field, the fingers point in the direction of the current.
Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
8 HRS	Electrodynamics				
4 hours	Electrical machines (generators, motors)	• State that generators convert mechanical energy to electrical energy and motors convert electrical energy to mechanical energy • Use Faraday's Law to explain why a current is induced in a coil that is rotated in a magnetic field. • Use words and pictures to explain the basic principle of an AC generator (alternator) in which a coil is mechanically rotated in a	Project: Build a simple electric generator Project: Build a simple electric motor	Materials: Enamel coated copper wire, 4 large ceramic block magnets, cardboard (packaging), largenail, 1.5 V 25mA light bulb. Materials: 2 pieces of	The basic principles of operation for a motor and a generators are the same, except that a motor converts electrical energy into mechanical energy and a generator converts mechanical energy into electrical energy. Both motors and generators can be explained in terms of a coil that rotates in a magnetic field. In a generator the coil is

		magnetic field • Use words and pictures to explain how a DC generator works and how it differs from an AC generator • Explain why a current carrying coil placed in a magnetic field (but not parallel to the field) will turn by referring to the force exerted on moving charges by a magnetic field and the torque on the coil • Use words and pictures to explain the basic principle of an electric motor • Give examples of the use of AC and DC generators • Give examples of the use of motors		thin aluminium strips 3cm x 6cm, 1.5 m of enamel coated copper wire, 2 lengths of copper wire, a ring magnet (from an old speaker) a 6cmx15cm block of wood, sandpaper and thumb tacks.	attached to an external circuit and mechanically turned, resulting in a changing flux that induces an EMF. In an AC generator the two ends of the coil are attached to a slip ring that makes contact with brushes as it turns. The direction of the current changes with every half turn of the coil. A DC generator is constructed the same way as an AC generator except that the slip ring is split into two pieces, called a commutator, so the current in the external circuit does not change direction. In a motor, a current carrying coil in a magnetic field experiences a force on both sides of the coil, creating a torque, which makes it turn. A note on torque: Know that the moment of a force, or torque, is the product of the distance from the support (pivot point) and the component of the force perpendicular to the object.
4 hours	Alternating current	• Explain the advantages of alternating current • Write expressions for the current and voltage in an AC circuit • Define the rms (root mean square) values for current and voltage as $I_{rms} = \frac{I_{max}}{\sqrt{2}} \text{ and } V_{rms} = \frac{V_{max}}{\sqrt{2}}$ respectively, and explain why these values are useful. • Know that the average power is given by: $P_{av} = I_{rms} V_{rms} = \frac{1}{2} I_{max} V_{max}$ (for a purely resistive circuit) • Draw a graph of voltage vs time and current vs time for an AC circuit. • Solve problems using the concepts of, I_{rms} V_{rms} P_{av}			The main advantage to AC is that the voltage can be changed using transformers (device used to increase or decrease the amplitude of an AC input). That means that the voltage can be stepped up at power stations to a very high voltage so that electrical energy can be transmitted along power lines at low current and therefore experience low energy loss due to heating. The voltage can then be stepped down for use in buildings, street lights, and so forth.

Table 2.3 below is the summary of weightings of topics as prescribed in the examination guideline for grade 12 and the discussed topic is bolded. Together with mechanics (63 marks), the topic of electricity and magnetism (55 marks) carry higher weights as compared to the other two topics.

Table 2.3: Weighting of prescribed content (physical sciences grade 12 examination guideline, 2014:5)

PAPER 1: PHYSICS FOCUS			
CONTENT	MARKS	TOTAL	DURATION
MECHANICS	63	150	3 HOURS
ELECTRICITY AND MAGNETISM	55		
WAVES SOUND AND LIGHT	17		
MATTER AND MATERIAL	15		

2.3.2 Discussion of the prescribed CAPS syllabus on electrodynamics

One of the concerning issues in this study, is the way electrodynamics concepts are progressing, linked and related to everyday life experience for better understanding. According to Table 2.2 the topics that relate to electrodynamics in the FET band progresses from Grade 10 to 12. In grade 10 they focus on magnets, magnetic fields of permanent magnets, magnetic field of the earth and magnetic field lines. Then in grade 11 they introduce electromagnetism, focusing on the production of magnetic field due to current in a wire and Faraday's law. Electrostatics is taught as a separate topic in grade 10 and not linked to electromagnetism in grade 11. There is no emphasis of how electrostatics fits into electromagnetism. Neither are the sources of electric and magnetic fields differentiated by charge always producing electric fields and magnetic fields only when charges are moving. Then in grade 12 they go straight to power machines, with specific reference to generators and motors.

In the researcher's view, the concepts are stagnant with missing links and with limited emphasis of important concepts such as induction. How induction comes in to the understanding of Faraday's law and the importance of understanding Lenz's law and finally to understand motors and generators are not indicated in Table 2.2. Faraday's law is not emphasised as a law under electromagnetic induction. It is treated more like a stand-alone concept (refer to column three of content coverage in Table 2.2). The progression as indicated in the CAPS document thus appears to be fragmented to the researcher. This can create serious gaps of network of concepts to understand electrodynamics as a unit and alternative conceptions are likely to form.

Another concerning aspect that is noticed in column 3 of Table 2.2 of the FET syllabus is the balancing of the cognitive levels as in Blooms taxonomy. One of the problems noticed with this FET syllabus coverage is that cognitive levels are compromised in the process as the curriculum designers did not take into cognisance the balancing of the cognitive levels of the syllabus and content. It is a concern that the content, concepts and skills (column 3) of Table 2.2 mostly start with words indicating lower levels of Bloom's taxonomy, e.g. "give examples", "know", "state", "use a rule and calculate / solve", (i.e. apply), "define", etc. Only a few higher order terms appear, for example "qualitative discussion", "research". The concepts to be learned should cover a range of cognitive skills which include high order questions like critical thinking, application of knowledge and ability to interpret analytically. The different cognitive levels should not only be covered but also be distributed to each section of the knowledge area to make the syllabus accurate and reliable. The cognitive levels of content should be balanced as this would improve subject knowledge and professional content knowledge and should collectively cover all knowledge skills.

Table 2.4: Recommended weighting of cognitive levels for examinations and control tests (DBE, 2011).

COGNITIVE LEVEL	DESCRIPTION	PAPER 1 (PHYSICS)	PAPER 2 (CHEMISTRY)
1	Recall	15 %	15 %
2	Comprehension	35 %	40 %
3	Analysis, Application	40 %	35 %
4	Evaluation, Synthesis	10 %	10 %

Table 2.4 provides a detailed description of the cognitive levels for assessment. It gives possible hierarchy of cognitive levels that can be used to ensure that tasks include opportunities for learners to achieve at various levels. From this table, a high percentage is allocated to level 2 and 3, meaning a lot should be assessed in level 2 and 3 concepts or knowledge area. The logic is that if the syllabus (Table 2.1) addressed more of level one concepts (knowledge recall), then learners would struggle to answer level two and three questions. The distribution of cognitive level in the syllabus, should speak to the cognitive level recommended for assessment. The two should tally if proper learning should take place. Knowledge and concepts to be

learned should balance and range from low, middle, to higher order according to Blooms Taxonomy (DBE, 2011:152-153).

2.4 PRACTICAL WORK IN THE FET SYLLABUS

The South African Department of Education describes physical sciences as a learning area that focuses on investigating chemical and physical processes and scientific enquiry (DoE, 2011). An overview of practical work as stated in the CAPS also dictates on how it should be implemented. According to physical sciences CAPS document (2011:11) *“practical work must be integrated with theory to strengthen the concepts being taught. These may take the form of simple practical demonstrations or even an experiment or practical investigation. There are several practical activities outlined alongside the content, concepts and skills across the FET curriculum”*. Some of these practical activities are executed as part of formal assessment tasks and others as part of informal assessment (physical sciences CAPS, 2011:11). In the South African context, practical work includes experiments, practical investigations, research projects and building scientific models. The CAPS document supports the argument that practical work is essential in physical sciences education (physical sciences CAPS, 2011:11). School based practical assessment tasks prescribed as formal assessment in the FET band are tabulated in Table 2.4.

Table 2.5: prescribed FET practical assessment tasks

Grade	Term	Prescribed Practical Activities Formal Assessment	Recommended Practical Activities Informal Assessment
10	Term 1	Experiment 1 (Chemistry): Heating and cooling curve of water.	Practical Demonstration (Physics) Use a ripple tank to demonstrate constructive and destructive interference of two pulses OR Experiment (Chemistry) Flame tests to identify some metal cations and metals.
	Term 2	Experiment 2 (Physics): Electric circuits with resistors in series and parallel - measuring potential difference and current.	Investigation (Physics) Pattern and direction of the magnetic field around a bar magnet. OR Experiment (Chemistry) Prove the Conservation of matter experimentally.
	Term 3	Project: You may do any of these topics or any other topic based on the Grade 10 content. Chemistry: Purification and quality of water. OR Physics: Acceleration. Example: Roll a ball down an inclined plane and using measurements of time and position obtain a velocity + time graph and hence determine the acceleration of the ball. The following variations could be added to the investigation: i. Vary the angle of inclination and determine how the inclination impacts on the acceleration ii. Keep the angle fixed and use inclined planes made of different materials to determine how the different surfaces impact on the acceleration. One could also compare smooth and rough surface etc.	Experiment (Physics) Roll a trolley down an inclined plane with a ticker tape attached to it and use the data to plot a position vs. time graph. OR Experiment (Chemistry) Reaction types: precipitation, gas forming, acid-base and redox reactions.
	Term 4		Experiment (Chemistry) Test water samples for carbonates, chlorides, nitrates, nitrites, pH and look at water samples under the microscope. Experiment (Physics) Conservation of Energy (qualitative)
11	Term 1	Experiment (Physics): Investigate the relationship between force and acceleration (Verification of Newton's second law)	Practical Demonstration (Physics) Investigate the relationship between normal force and maximum static friction. Investigate the effect of different surfaces on maximum static friction by keeping the object the same. OR Experiment (Chemistry) Investigate the physical properties of water (density, BP, MP, effective as solvent, ...)
	Term 2	Experiment (Chemistry): The effects of intermolecular forces: boiling points, melting points, surface tension, solubility, capillarity, ...	Experiment (physics) Determine the critical angle of a rectangular glass (clear) block. OR Experiment (Chemistry) Boyle's law OR preparation of PbO ₂ from Pb(NO ₃) ₂
	Term 3	Project: You may do any of these topics or any other topic based on the Grade 11 content. Chemistry: Exothermic and endothermic reactions (examples and applications) OR Physics: Snell's Law	Experiment (physics) Obtain current and voltage data for a resistor and a light bulb and determine which one obeys Ohm's law. OR Experiment (Chemistry) Investigate natural indicators for acids and bases
	Term 4		Experiment (Chemistry) Redox reactions - one synthesis, one decomposition and one displacement reaction.
12	Term 1	Experiment (Chemistry) Preparation of esters	Experiment (physics) Draw a graph of position vs. time and velocity vs. time for a free falling object. AND Use the data to

			determine the acceleration due to gravity. OR Experiment (Chemistry) Reaction of alkanes and alkenes with bromine and potassium permanganate OR making a polymer like "slime" or "silly putty".
	Term 2	Experiment (Chemistry) How do you use the titration of oxalic acid against sodium hydroxide to determine the concentration of the sodium hydroxide? OR Experiment (Physics) Conservation of linear momentum.	Investigation (Physics) Perform simple experiments to determine the work done in walking up (or running up a flight of stairs). By timing the run and walk (same flight of stairs) one can enrich the concept of power. OR Investigate Conservation of linear Momentum OR Experiment (Chemistry) Rate of chemical reactions with sodium sulphite and hydrochloric acid OR chemical equilibrium.
	Term 3	Experiment (physics) Part 1 Determine the internal resistance of a battery. Part 2 Set up a series-parallel network with known resistor. Determine the equivalent resistance using an ammeter and a voltmeter and compare with the theoretical value.	Investigation (Physics): Set up a series-parallel network with an ammeter in each branch and external circuit and voltmeters across each resistor, branch and battery, position switches in each branch and external circuit. Use this circuit to investigate short circuits and open circuits. OR Experiment (Chemistry) Investigate electrolytic and galvanic cells.
	Term 4		

The current curriculum (CAPS) integrates practical work with theory to support the content that is being learned. These might be in the form of practical works, demonstrations or investigations. There are several relevant hands-on activities set in line with content knowledge, theory and skills in the document (refer to Table 2.3). For grades 10 and 11, prescribed practical work is done annually as formal assessment (one formal experiment per quarter and two informal practical work, one per term plus a research project). For grade 12 classes, three prescribed practical work must be completed each quarter: One from physics plus two from Chemistry, or 'one' Chemistry plus 'two' p practical, adding up to three as formal assessments. Practical work occurs across the curriculum and weighs 40% of school-based assessments (SBA) (physical sciences CAPS, 2011:11, 130). It is important to give the learners a chance to expand and improve their practical skills in the physical sciences background and demand. It is therefore also crucial to give teachers the chance as well to improve their practical skills for the teaching of electrodynamics (DoE, 2011).

Hands-on experiments' focal point is the practical features and the procedures that are essential for scientific inquiry and problem-solving skills. Unfortunately, the sampling group indicated that few schools have laboratories (refer to Table 6.1) and that may be the case in general. For those that have laboratories, teachers lack confidence to get into these laboratories to do practical work. The importance of

practical work as indicated above are certainly compromised despite their need in the learning and teaching of physics. Hence, many school teachers themselves are not confident in teaching, never mind effectively (Kriek & Grayson, 2009:185).

2.5SUMMARY

This chapter outlined the historical development of scientific concepts and laws that are related to or led to electrodynamics. The historic development can serve as a guide for effective conceptual development in a teaching sequence. This chapter further offered a discussion of the overall FET syllabus. It seemed as if curriculum did not take historic development into account for the relevant conceptual developments to guide the progression of concepts. The syllabus further seemed not to be balancing the Bloom's taxonomy in a manner that will address the demand of the subject. Practical work is prescribed by the CAPS to support understanding of the theory. The next chapter reviews challenges in the learning of electrodynamics.

CHAPTER 3: CHALLENGES IN THE LEARNING OF ELECTRODYNAMICS

3.1INTRODUCTION

In the learning of electrodynamics, learners encounter a high level of abstraction. Teachers and learners consequently find some concepts being difficult to grasp (Chabay & Sherwood, 2006:329). Cornwall (2000:217) stated that “physics can appear to be a remote, mysterious and an incomprehensible subject to many of those learning it, even at the university. Thong and Gunstone (2007:1) stated that learners’ progress to higher levels of their schooling, having pre-knowledge of concepts based on their everyday observations and classroom interaction during lessons. When learners enter tertiary levels, they come across more abstract concepts. Some manage to merge the new information into the correct scientific knowledge. Others still hold on to some of the pre-conceptions which are apparent in the form of naïve explanations of electromagnetic processes (Thong & Gunstone, 2007:1).

Despite the effort put to relate physics to its achievements and applications in everyday life, it is still perceived by many as a difficult abstract subject ultimately fit only for intelligent people and geniuses. Although the modern world is largely a product of the applications of physics to satisfy our needs and demands, physics often still seems to be remote from our immediate experience (Cornwall, 2000:217). Struggling learners and teachers perceive the subject as an obscure and an incomprehensible subject whose theories are difficult to learn.

This chapter reviewed problem areas or challenges in the learning of electromagnetism and gave an idea of difficult concepts to give attention to in this study. The chapter focused on the challenges encountered during learning, thereby obstructing or prohibiting learning of concepts related to electrodynamics. The chapter reviewed alternative conceptions of concepts related to electrodynamics and how they developed (causes). The roots of alternative conceptions as challenges contributing to confusions and difficulties experienced during learning were discussed in section 3.4. The detailed discussions of alternative conceptions that were identified and reviewed in this chapter (section 3.4.) were then summarised and

tabulated in Table 3.1 for referral in this study. The constructivist learning theory underlies the discussion of conceptual difficulties that learners experience in learning electrodynamics in this chapter.

3.2CONSTRUCTIVISM

This section reviewed the constructivist learning theory, according to which learners build new knowledge from existing knowledge (Ausubel, 1968). According to the constructivist view, learners come into science classrooms already having primitive and pre-conceived conceptions with perspective that may be related and applicable to what they are supposed to learn, but these ideas are often scientifically incorrect (Redish, 2001:30). Formation of concepts may arise through the interaction between previously accumulated knowledge and current data (Watts, 1983:52)

A major challenge of the physical sciences teacher is that learners enter a class with alternative conceptions as part of their existing knowledge. Since alternative conceptions differ from the accepted scientific concepts, they cannot serve as proper foundation for the construction of scientific knowledge and understanding. To accomplish conceptual development towards correct scientific conceptions in a constructive way, learners' alternative conceptions must be discredited and they must perceive the new concepts as plausible. White (1988:48) stated that learning science involves understanding and that the patterns of associations between its elements are important. He explained understanding as the ability to use the correct knowledge and to cope with new situations and or new formation of concepts that links to the existing knowledge. In that manner, concepts build in a constructive manner and learning become plausible.

Everyday experiences are inadequately incorporated in teaching during learning, thus forming new concepts with no links to the existing knowledge. When pre-conceived knowledge is not integrated with the new learning process, it will not make the learning experience relevant to the learner (Beer, 2010:27). Teaching sequence should lead to opportunities to connect the classroom experiences to the outside world practices and provide an opportunity to chain and string the information into new conceptual framework and in a constructivist manner. For effective learning to

take place, teaching must be tailored and sequenced towards the learners needs and should be in line with the constructivist approach.

Constructivism views the learner as playing an active role in learning and making sense of the new knowledge (Woolfolk, 2010:310). In a constructivist view, learners construct knowledge by relating and linking what is to be learned to what is known. They use the pre-conceived knowledge to productively create a reaction to the new acquired knowledge (Redish, 2001:30). The information processing claims that knowledge construction is a representation of the outside world and should reflect it. Learning is affected by direct teaching, feedback and explanation and connection of the basic knowledge or existing knowledge is important to the formation of the new information. Therefore, learning should consist of exploration, discovery and investigations (Woolfolk, 2010:313). The constructivism model of learning is a radical departure to rote learning and stands to be recommended in physical sciences learning.

3.3ROTE LEARNING

In order to promote effective learning in physical sciences critical thinking should be encouraged over rote memorisation. The consequence of rote learning in multiple studies showed that even after completing a tertiary course, learners' knowledge of the fundamental concepts covered is generally poor (Bagno & Eylon, 1997:726-736). Learners have been able to avoid a deep conceptual knowledge base by memorising most of the different situations to be covered on one particular test. Learners are able to learn how to solve problems through memorisation of techniques, without increasing their knowledge of the essential processes taking place in the problem. The ability of learners to retain this information over the long term is poor, especially when they have to memorise a whole set of new situations. If learners understand the underlying concepts connecting different phenomenon, they should be able to derive the correct learning approach to all related problems after completing courses (Beer, 2010:17-18).

It has been argued by that learner conceptions are fragmented and not interrelated, resulting to content gaps and alternative conceptions on topics such as electromagnetic induction. Guisasola *et al.* (2003: 450) believed that fragmented

content knowledge in electromagnetic induction is the results of learners being taught applications, without teaching the basic theories thoroughly because teachers themselves have alternative conceptions. They further stated that it would mean that what was previously learned must have been achieved through rote learning and having difficulties to reason would imply that alternative conceptions were not modified by instruction. Rote learning creates content gaps, concepts confusion, alternative conceptions and eventually concept difficulty during conceptual development of new information or knowledge. Saglam (2010) argued that the understanding of new learning contents implies recognising the relationship between the new material and the knowledge possessed already. Science education research have revealed that learners in science courses experience challenges during the development of new science concepts and end up resorting to rote learning, a contributory factor to alternative conceptions.

3.4ROOTS OF ALTERNATIVE CONCEPTIONS IN ELECTRODYNAMICS

In the context of Science education, the term alternative conception refers to the conceptions which are in some aspects contrary to, or inconsistent with the current intention of Scientist. Alternative conceptions can have a variety of sources, such as: misinterpretation of everyday life experience and even be formed in the classroom if held alongside the scientific ideas. Besides, there are different factors that can lead to the development of alternative conceptions and some are discussed in this study.

Learners' conceptual difficulties may be coursed by disconnection of knowledge linking one topic to the other, for example in physical sciences, mismatch of electricity and Magnetism related to the learning of electrodynamics (Thong & Gunstone, 2007:2). Raduta (2005:34) stated that, sometimes in text books, there are information that needs to be stressed and given attention for conceptual understanding. They will be written very briefly in a way that tempts learners to believe that they are not significantly important for learning or recalling. At times the textbooks phrasing is very vague, unclear and even confusing, in that way leading the learners to misunderstanding of concepts that need to be learned. Some textbooks would arrange the information within a single chapter, without any comprehensive effort to put or organise the overall information at a broader and

inclusive way, to allow learners to see connections between different concepts or topics and real life situations (Raduta, 2005:34).

Other factors that may cause alternative conceptions are the incorrect use of analogies and the wrong methodology or irrelevant methods used in the teaching and learning of Science. Redish (2002:28-29) mentioned that learners use their everyday language as an easy way out to explain more complex scientific processes and phenomena. Redish refers to these easy ways out statements as “primitives and naïve”. He explained that learners often make the correct observation on scientific processes, but inaccurately link the concepts to the incorrect variables and make incorrect generalisations and conclusions. Redish further mentions that these primitives and naïve statements contain correct elements within them and could be used to lay foundation for learners to construct new scientific knowledge.

These are examples of sources of alternative conceptions that make a learner to make incorrect generalisations and conclusions or to link the concepts to the incorrect variables. Alternative conceptions are resistant to change because they become deeply rooted because somehow they are intelligible, meaningful and work for the learners. Concepts related to electrodynamics are areas of science in which many alternative conceptions have been identified and exist. In view of the problems posed by alternative conceptions in these areas, they were reviewed in the next sections so that corrective strategies to address them can be attempted.

3.4.1 Conceptual difficulties in electricity and magnetism (basics of electrodynamics)

Guisasola *et al.* (2003:444) conducted a study on university engineering and physical sciences learners that dealt with electromagnetic phenomena. The study covered concepts of electromagnetism (electricity and magnetism) as a source of magnetic field and their interaction, also the attraction among magnets and ferromagnetic materials and between two spirals of current. The problems and challenges of learners to identify different sources of magnetic field as magnets and currents were reported. In their study, they included questions that required more elaborated answers on electromagnetism, for broader understanding of concept difficulty. Some learners explained the attraction of a paper clip to the magnet as

induction. They reasoned that metals have delocalised electrons and believed that the magnetic field that is produced by the bar magnet polarise the magnetic material by attracting or repelling the electrons, depending on the nearest magnetic pole (Guisasola *et al.*, 2003:444, 450-451).

The study of Bagno and Eylon (1997:726) explored the conceptions of university Science learners of electric and magnetic concepts as the basic concepts of electrodynamics. Their research intended to explore if the normal traditional teaching of electrodynamics can present a structured and sufficient representation of knowledge. The conceptualising of fields as not being concrete and field lines as not being real entities were inadequate and misinterpretations persisted after instruction. Learners incorrectly perceived magnets to produce magnetic fields because they have field lines. Guisasola *et al.* (2003:453) further supported that learners seem to attribute a real existence to field lines as opposed to a representation used to simplify the existence of magnetic fields. Learners think that field lines are generated in magnets, going out from North to South and those lines are the ones producing the magnetic field in space around the magnet. The learners thought that magnets create field lines called a magnetic field. Consequently, they identify the field lines as if they are real and not as a vector representation of magnetic field in space. They indicated that a perception of field lines having a physical reality was likely expressed as a need for 'real contact' of the field lines. Guisasola *et al.* (2003:453) stated that these explanations that learner give, came with them from secondary schools, which may have been caused by rote learning and teaching sequences used as teachers themselves seemed not confident enough in teaching this topic effectively. The alternative conceptions possessed by science teachers create a room for misunderstanding of electromagnetic concepts not plausible (Thong & Gunstone, 2007:42).

West (2009) also indicated in his study that the electric content was mastered better than the magnetic content and its section of finding the magnetic field from a current. Learners do not know that current electricity is a source of magnetic field. He found that learners were unable to determine the magnetic field from a long, straight wire and indicated that such a deficiency showed a strong lack of knowledge that would prevent a learner from being able to understand other field concepts. Guisasola *et al.*

(2003:444) believed that the magnetic field and its sources are an important requirement and an essential for the understanding of electromagnetic phenomenon. They analysed learners' understanding of the magnetic theory and the concept of magnetic field and its sources which they believed were the basic concepts of electromagnetic phenomena. Electric field and magnetic field could not be marginalised between electrostatic and electric current interchangeably.

Learners' challenges in conceptualising the connections between the electric charges and magnetic fields were identified by Bagno and Eylon (1997:726-735). Learners were to make a distinction of what would happen when electric charges were positioned close to the north and south poles of permanent magnets. They were required to rank these scenarios from the strongest repulsion to the strongest attraction, based on the magnetic force exerted on a point charge. They established and noted some alternative conceptions. The majority of the learners indicated the N Pole as if it was positively charged. The response would then mean that the majority of learners believed that the magnetic poles were electrically charged and that the magnetic poles would attract or repel protons or electrons, depending on the type of the charge on that particular pole (Bagno & Eylon, 1997:726-735).



Figure 3.1: Moving charge between poles of the bar magnets (Bagno & Eylon, 1997: 727)

A similar concept investigated by Bagno and Eylon (1997:726-735) is shown in Figure 3.1. This time their problem situations had an electric charge moving at a right angle to the field between the pole faces of two permanent magnets, in the plane of the magnetic field. Interchanging the polarities of the two magnets and the sign of the charge, several similar problems were given to the learners.

By analysing their answers, the author could detect the strategies used by learners. The learners were asked the same question for all the similar problems: Which way will the electric charge be pushed as it moves through the area between the poles? The possible answers were that the charge will move toward magnet A, or the charge will move toward magnet B. The most popular individual answer was the one

that took the N-pole as being, or acting as though it was, positively charged (Bagno & Eylon, 1997:726).

The respondents have been taught previously to find the sense and direction of the Lorentz force using the right-hand rule. They turn to use the wrong hand, right or left and also when the charge is negative and not positive, the rule would still not apply. The learners ought to learn to apply the vector product where two magnetic fields from different sources interact or interfere (B_{net}) for different orientations. A general and major alternative conception that was prominent among learners was the expression of the Lorentz force. Learners thought that the direction of the current passing through the magnetic field should always be at 90° to each other. The main cause of this pre-conception is that the most part of applications of electromagnetism usually it deals with a charged crossing the magnetic field at 90° . As is also mentioned above, another reason is that the learners are not acquainted to the application of vector products (Bagno & Eylon, 1997:726).

Mauka and Hingley (2005:1165) investigate the same concept of the vector product giving the Lorentz force. The question refers to Figure 3.2 below and asked if a net magnetic force was exerted on the loop while it was moving up; and require the direction of the force and an explanation. They gave the correct answer to say the wire does exert a resultant force on the loop due to its motion in the magnetic field B produced by the line current. In this problem, the magnetic field above the straight wire was into the page causing the current in the loop to flow clockwise. Raduta (2005:5-12) believes that difficulties to interpret Figure 3.2 arose out of two issues: (i) the deduction of the understanding of some interaction and association, (ii) learners' need for a causal effect, somehow a movement to let them familiarise with the existence of magnetic field. Learners accept the existence of a cause only when they can imagine an effect. Most learners said that there was a net force, but very few obtained the correct direction. The most prominent cause for incorrect answers was again indicated as the incorrect application of the vector cross product in the example (Mauka & Hingley, 2005:1167). They argued that applying the vector product clarifies better than applying the right-hand rule to say the net force is at 90° to the velocity of the charge and the magnetic field acting on the same plane and to

emphasise that the angle between the moving charge and the magnetic field is not automatically equivalent to 90 degrees (Bagno & Eylon, 1997).

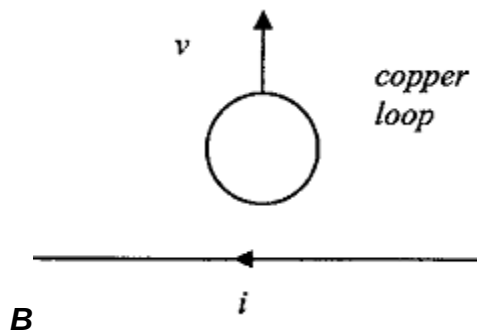


Figure 3.2: Solenoid moving perpendicular to the current carrying straight conductor (Mauka & Hingley 2005:1165)

The equation of the Lorentz force, $\vec{F} = q\vec{v} \times \vec{B}$, specified another big source for learners' alternative conceptions to be the mathematical skill that they are lacking and need to be learned to understand electrodynamics. The majority of the learners, experience challenges to apply scalar and vector products, which is primary to the learning and understanding of electrodynamics and could be interpreted using equations (Bagno & Eylon, 1997:734).

3.4.2 Conceptual difficulties in electromagnetic induction and applications

Planinic (2006) conducted a study in Croatia and America and revealed that learners had conceptual difficulties and challenges largely in the area of electromagnetism. The study diversely compared the conceptual problems in the areas of electricity and magnetism, which forms the basis of electrodynamics. The most difficult area found among both groups was electromagnetic induction. According to Raduta (2005), conceptions related to electricity and magnetism is much more perceptive and understandable than electromagnetic induction.

Raduta, 2005:5-12) indicated learners' difficulty of the application of Faraday's law. He indicated that many learners had problems to conceptualise how EMF is induced in a closed circuit. Furthermore, learners have trouble understanding when and how a current is induced in a loop and the direction of the induced current. Another was in understanding why current cannot be induced in the loop when the loop moves parallel to the current. In this case learners answered incorrectly that there was an

induced current and the most common incorrect reasoning was that the presence of the magnetic field or the magnetic flux alone was the cause of the induced current rather than a change in magnetic field or flux. If the magnetic flux through the loop does not change, no electric field is induced according to Faraday's law. The second most common incorrect reasoning was an inappropriate application of the vector cross product or misuse of the right-hand rule.

Bagno and Eylon (1997:727) also indicated that many of the textbooks did not stress the concept of the change in the magnetic field and its relation to the generation of electricity, even though the induced EMF was emphasised in the associated theory. They say it was anticipated that learners might not connect the induced EMF to the production of an electric field. With regard to Lenz's law, Thong and Gunstone (2007:42) stated that learners replaced 'being in opposite direction' for 'opposes the changes'. Learners would resort to apply the right-hand-rule without the correct and appropriate way of understanding. The majority assumed that the direction of velocity or movement of the electric charge was always at 90° to the applied magnetic field. Consequently, Bagno and Eylon (1997) emphasised that the majority of the learners also believed that the direction of the electric charge in a magnetic field was circular.

Kotoka (2012) conducted a study on the learners' ability to use mathematical skills in the learning of electrodynamics. Learners were asked to give a definition of magnetic flux and to elaborate on its physical importance and implication. Kotoka established that the majority of the learners could state the formula for magnetic flux, but were unable to define it, or even to relate the formula to easy problems. The conclusion was that many learners' understanding was disconnected and applied incoherently. The great importance of electrodynamics in physical sciences and in technological applications leaves no space for alternative conception in electrodynamics and needs to be addressed from the teachers' level first (Guisasola *et al.*, 2003:444).

3.4.3 Concept confusion as a root of alternative conceptions

Initially, the basic concepts of electrodynamics (electricity and magnetism) had been regarded to be two separate entities, though this perception was changed. On both electricity and magnetism, the driving force experienced by a positive or negative charge is the same force. There are main effects resulting from these interactions, as stated below by Beer (2010:75-76).

“The force of attraction or repulsion between two charged particles is inversely proportional to the square of the distance between their centres, and that opposite charges attract, like repels”.

With the magnetic poles, they attract or repel each other in a similar manner but always come in pairs unlike in electric charges: every North Pole is attached to a South Pole.

The similarity between magnetic poles and electrostatic charges goes well beyond the rules for attraction and repulsion. In an attempt to measure the magnetic force that two magnetic poles exert upon one another and how it varies with distance or the strength of the poles, it was found that they behaved according to a law of the same form as Coulomb's law for the electrostatic force. It has also become clear that the electrostatic force and the magnetic force are just different aspects of one fundamental electromagnetic force (Beer, 2010:75-77)

The analogies that learners make between the electric and magnetic field were additional sources of alternative conceptions. There has been confusion regarding the magnetic field of a bar magnet and the electric field between two opposite round charges. The fact that there can never be a single magnetic pole means that a magnet is always at least a dipole and there can never be fewer than two poles. According to Beer (2010:75-77), physicists have spent considerable effort looking for magnetic monopoles, particularly consisting of a single isolated magnetic pole and have found no conclusive evidence that such entities exist. Breaking a magnetic dipole in half always produces two dipoles. Positive or negative charges can be isolated, but that is not the case with magnets. Breaking a magnet into two halves will always produce two poles (i.e. a dipole). This is one respect in which magnetic

poles are not similar to electric charge: positive or negative charge can be isolated, but that is not the case with magnets (Beer, 2010:75-77). Conversely, electric dipoles can be produced by opposite charges separated by a small distance. The electric field lines between two oppositely charged particles starts from the positive charge and ends at the negative charge. It turned out that a magnetic field could indeed be defined in which the field lines showed the same pattern for a magnetic dipole as the electric field lines did for the electric dipole (Beer, 1999:266). Such similarities can cause confusion among learners' regarding electric and magnetic fields, such as:

- They attribute electric features to magnets. For example, learners may think that the north pole of a magnet is positively charged and the south pole negatively.
- They do not distinguish between the sources of magnetic and electric fields, e.g. some learners ascribe both magnetic and electric fields to charges, whether stationary or in motion.
- They also do not perceive magnetic field lines as closed loops, but think that they originate at the North Pole and stop at the South Pole.

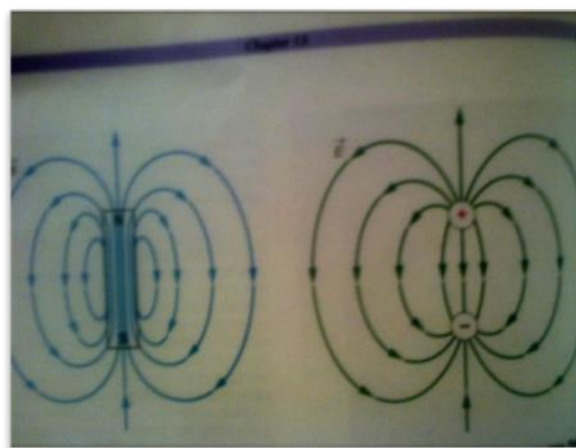


Figure 3.3: Similarity of field patterns between the magnetic dipole and electric dipole (Beer, 2010:75-77)

Beer (2010:75-77) then gave a concluding suggestion that in order to handle these alternative conceptions, the teacher can start by evoking learners' awareness of

differences between magnetic and electric interactions. This is then followed by a study of the relationship between an electric current and magnetic field as it occurs in the electromagnet.

Guisasola *et al.* (2003:444) pointed out that secondary school learners and university learners lacked high knowledge on the scientific nature or interpretations of magnetic fields and its phenomena. It was found that majority of them were failing to recognise the source of magnetic field and **confused the concepts of magnetic force and magnetic field**. Learners do not know that charges that are in motion produce magnetic field. The study showed that learners could not significantly and meaningfully display the proper understanding of the magnetic field representation and most of them had a non scientific model to explain magnetic phenomena. An example was cited on the learners understanding and differentiation between of the stationary charge producing the electric field and a moving charge producing the magnetic field. Learners need to familiarise with processes that relate to the sources of magnetic field, such as the ones produced by permanent magnets and those created from moving charges. Some learners thought electrical charges produce magnetic fields regardless of them moving or not, which shows confusion. According to Guisasola *et al.*, learners considered stationary charges to be producing magnetic field. Learners' explanations confused the source of electric field and magnetic field. Guisasola *et al.* (2003:453) also found confusion between the field and the force it exerts. Learners confused two concepts that are epistemologically not the same but closely related, namely, 'magnetic field and magnetic force'. The one is the source of the phenomenon (the field) and the other is the way this source of the phenomenon interact (the force). There was a confusion of the relationship between spirals of current (i.e. current in a solenoid) and magnets. Magnetic field produced by magnet was understood to be due to moving electrons inside the magnets as is happening with the solenoid. The movement of electrons of the atoms of the magnetic domains create microscopic magnetic dipoles that are aligned in the same direction, as a result creating a magnetic dipole at the macroscopic level and generating the magnetic field of the bar magnet.

The electrical explanations and arguments of learners was that electric charges distribute such that the northern pole build up the positive charge and the southern

pole accrued the negative charges. The electrical analogy was used to describe the magnetic processes and the confusion was brought by that analogy. Some of the answers were that magnet is an element that was made up of two parts that were positively and negatively charged and penetrated a circular magnetic field that were moving from pole to pole". In this quote, electrical and magnetic fields are mixed. The electric charge is qualified to produce both magnetic and electric fields, exclusive of mentioning being in motion or stationary (Guisasola *et al.*, 2003:450). The same confusion was also cited by Raduta (2005:5-12) that learners calculated the magnetic field in instances where the charges were stationary or moving parallel to the magnetic field.

The concept difficulty of why current cannot be induced in the loop when the loop moves parallel as stated by Raduta was discussed in paragraph 3 of 3.5.2 above. Mauka and Hingley (2005:1165) also investigated the same concept but differently; the copper loop moving parallel to a current carrying wire, refer to Figure 3.4 below. The velocity of the loop and the distance between the wire and loop was changing even though it was moving parallel. The question was asked if a current was induced in the loop and, if so, the direction of the induced current. One of the reasons given for the induced current were that the current in the loop moves opposite to that in the wire as a result of Lenz's law and that an **electric field** rather than a **magnetic field** induces the current (Mauka & Hingley 2005:1165).

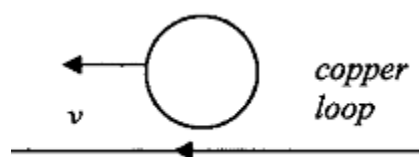


Figure 3.4: Solenoid moving parallel to the current carrying straight conductor (Mauka & Hingley 2005:1165)

Another problem that was documented by Raduta (2005:5-12) was that learners had a problem to find the direction of the induced voltage. The problem was created by the vague and unclear encoding, which brought about confusion. Raduta (2005:5-12) indicated that textbooks also suggest sentences that teachers will not explain confidently to learners and could simply interpret and explain these statements wrongly. For example, **oppose the change** could be easily interpreted as meaning

being in the **opposite direction**, thereby confusing the two. Mauka and Hingley (2005: 1165) agree with Bagno and Eylon's findings about difficulty to determine the direction of induced EMF. He used a figure as an example similar to the one above, but now this time the copper loop moves perpendicularly away from the wire. The question asked if a current was induced and if yes, what its direction is. The correct answer is that a current is induced in the clockwise direction. The magnetic flux through the loop changes as the loop moves away from the wire. Thus, according to Faraday's law a current is induced in the wire, this by Lenz's law is in a direction such as to produce magnetic flux to resist the change in flux.

Learners thought the amount of current that was produced, was directly proportional to the magnitude of the current in the coil of the solenoid. Bagno and Eylon (1997) as stated by Thong and Gunstone, (2007:24) observed that learners in their study had "a common confusion that in magnetic induction, **the induced field is opposite in direction to the field which induces it**", rather than opposite in direction to the change in the field inducing it. This confusion relating to the 'change in the field,' seemed minor but impacted strongly on learner conceptions of electromagnetic induction.

Thong and Gunstone (2007:42) also observed that learners had a perception that the current that is induced in the circuit was directly proportional to the magnitude of the current set in the solenoid. That is, an increase of current in the solenoid was accompanied by an increase in the induced current. The acceptable conception would be an increase in the rate of change of current in the solenoid would generate an increase in induced current.

The purpose of this chapter was to present and to outline an overview of the main areas of alternative conceptions covered in the literature and to identify those that are not covered and suggest possible reasons for these alternative conceptions. A summary of these alternative conceptions is tabulated in 3.1 below.

3.4.4 Summary of alternative conceptions in this chapter

Table 3.1: Summary of the reviewed alternative conceptions on concepts related to electrodynamics

ALTERNATIVE CONCEPTIONS		REFERENCES
1	Charges cannot move in an insulator, therefore there is no electric current.	Bagno & Eylon, 1997:726-735
Sources of magnetic fields		
2	Electrical charges generate magnetic field whether or not they are in motion	Bagno & Eylon, 1997:726-734
3	Because we have electric charges, we should definitely have magnetic charges.	Bagno & Eylon, 1997:726-734
6	If the electric field is created by electric charges, then also the magnetic field should be created by magnetic charges.	Bagno & Eylon, 1997:726-734
4	Learners think of magnetic poles as being electrically charged, taking the North pole as being positively charged and South pole as being negatively charged.	Raduta, 2005:35
Fields and interactions		
5	Magnets interact with static charges (the N pole attracts negative charges and the S pole attracts positive charges).	Bagno & Eylon, 1997: 726-734
	Symmetry exists between electric and magnetic fields	Bagno & Eylon, 1997: 726-734
6	Fields are conceptualised as physical thing and field lines as real entities in space, and not as a vector representation in space around the magnets.	Guisasola <i>et al.</i> , 2003:452 Thong & Gunstone, 2007:42
Electromagnetic induction		
	Learners have been taught in almost all the books to find the sense and direction of the Lorentz force using the right hand rule, which is not consistent for all the situations.	Bagno & Eylon, 1997:726
	Only an electric or magnetic field is necessary for an induced current, not a changing flux.	Mauka & Hingley, 2005: 1165
9	Application of Faraday's law show difficulties in understanding the induced EMF and how it is produced, for example, the angle for current to be induced is not considered, but movement only.	Raduta, 2005:5-12
10	Learners do not relate Lenz's law or induced EMFs to the production of an electric field.	Bagno & Eylon, 1997: 726-734
11	Induced current varies proportionately with current in solenoid. The	Thong & Gunstone,

	magnitude of the induced current is directly proportional to the magnitude of the current in the coil of the solenoid.	2007:42
12	When determining the direction of the induced EMF 'oppose the change' is interpreted as being in the 'opposite direction'	Mauka & Hingley, 2005: 1165

3.5 SUMMARY

Learning is looked at today as how learners construct their individual understanding from personal experiences. It is well accepted in the physics education research community that learners bring a whole set of conceptions with them into class and eventually into their teaching career. It is necessary to recognise conceptually both curriculum and instruction to promote meaningful learning to displace alternative conceptions (Beer, 2010). When educators think about learning, they should think about how learners organise and connect their personal experience and understanding, their knowledge application and expansion of their understanding (Kotoka, 2012). Effective teaching requires that learners should actively take part and relate new ideas to their own experiences. Meaningful learning should take place for knowledge to be sustained, which takes us to ways or methods that can be used to ensure knowledge sustainability. These ways and methods are discussed in the next chapter (Saglam, 2010).

The next chapter reviews possible strategies and methods that can sustain knowledge, or cause a relatively permanent change in an individual's knowledge or behaviour. The literature reviews present current issues on the teaching and learning of Electromagnetism on FET level, with more focus on the way it should be presented by teachers to the learners. The chapter impacts positively on imparting and gaining more knowledge of teaching and instructional models for conceptual development to be used in the empirical research of this study.

CHAPTER 4: TEACHING METHODS AND INSTRUCTIONAL MODELS FOR CONCEPTUAL DEVELOPMENT

4.1 INTRODUCTION

The literature review of this study was steered at presenting the existing challenges on the teaching and learning of Electrodynamics in FET schools, with more focus on the ways it can be presented with understanding. This chapter reviews research-based methods, good strategies and different approaches for effective teaching in physical sciences. The reviews of teaching models were directed at assisting the researcher to develop a teaching sequence that would achieve the aim and objectives of this study.

Scherr and Redish (2005) have reported that, at university level, instructors use different indicators to determine if their learners are conceptualising the content and concepts taught in physics in a scientific acceptable way. Their findings suggest that learners can have enormous and diverse experiences in different modules and units of the same program when taught by different teachers or lectures, only because of different teaching models used. Guisasola *et al.* (2003:444) have mentioned that, even after an extensive period of time teaching electromagnetic field theory, the majority of the learners could not show or register any improvement of meaningful learning on the basic concepts. They have argued that it could mean the learners' mental models may not have developed adequately because of instruction and the teaching models applied during the learning process.

This study was conducted in the constructivist learning theory, according to which learners build new knowledge from existing knowledge (Ausubel, 1968). A major challenge of the physical sciences teacher is that learners often enter a class with alternative conceptions as part of their existing knowledge. To accomplish conceptual development towards correct scientific conceptions in a constructive way, learners' alternative conceptions must be discredited and they must perceive the new concepts as plausible. Sequencing subject matter should be in a constructive manner for conceptual development to progress successfully and effectively in a meaningful way during teaching (Gunter *et al.*, 2007:34).

This chapter reviews different instructional models and strategic methodologies to approach scientific learning processes and sequences that can promote conceptual development in constructive learning. The concepts of teaching sequence and conceptual development are clarified in sections 4.2 and 4.3 respectively. Section 4.4 reviews two major processes of teaching for learning, the teacher-centred approach and learner-centred approach. Section 4.4 is further elaborated by sub-sections, the traditional teacher-centred approach and the constructivist learner-centred approach. Conceptual refinement as conceptual development method is discussed in section 4.5, followed by interactive strategies in 4.6. The last part (section 4.7), gave a brief discussion about models and analogies as tools for learning abstract concepts.

4.2 TEACHING SEQUENCE

According to Gunter *et al.* (2007:34), a teaching sequence focuses on the arrangement of the content knowledge within a topic and the way it is structured. For example, the order and the sequence of the content and skills in fundamental subjects are generally structured from simple to complex. Similarly, the activities of teaching for learning should be arranged and sequenced accordingly for effective learning to take place. Learning experiences must be sequenced logically and orderly and should connect concepts to be learned to the learners' pre-conceptions (Gunter *et al.*, 2007:34). Learners' existing perceptions and pre-conceived knowledge, or any other challenge prohibiting them to understand or to conceptualise new content knowledge and phenomena, should be used to direct the selection of the content to be taught and the instructional interventions thereof. More attention ought to be given to the order and the logic in which the content is sequenced and presented. Conceptual development methods and strategies should pay attention to the introduction of concepts and the sequence in which new concepts are developed with the intention to avoid the development of new alternative conceptions and to address existing ones.

According to Duschl *et al.* (2011:131-135), learning progressions, teaching sequences and experiments are elements for conceptual development research programs in science education. Learners' conceptual development of scientific knowledge encompasses processes and mechanism about new ways to perceive

natural phenomena. Elaboration, reorganisation or refinement of existing knowledge is required. Knowledge can progress with the aid of well-designed sequences of activities that direct learning. It engages learners in a successively more refined way of knowing and thinking about concepts and practices. Although considering the organisation and alignment of concepts as important for learning, teachers need also to be attentive to the way that learners reason and should permit growth and development for conceptual understanding. Progression and sequencing of concepts for learning should engage learners in building and refining concepts in a constructive way for better understanding of scientific practices (Duschl *et al.* (2011).

From the cognitive learning theory, some principles that the teacher should keep in mind when setting out to design a teaching sequence for conceptual development, were mentioned by Gunter *et al.* (2007:4), namely:

- The cognitive level attained by the learner should improve their intellectual capability.
- Their patterns of perceptions and understanding should be modified during the learning process.
- The ideas developing in one's mind is distinct and exceptional. The learners' level of thinking and understanding is different.
- Proper understanding is enhanced if knowledge is useful and practical to real life
- The learner need to organise and conceptualise concepts and place it in their conceptual framework.

Mäntylä (2012) specified two crucial areas of constructing and learning physical sciences content information and its processes. Firstly, he indicated that to know the structure means knowing the framework of the content knowledge and secondly, he pointed that to know the processes would mean having the basic knowledge, the construction of the framework and the justification thereof. According to White (1988:46), a person's concept about a particular label is a collection of all memory elements that a person associates with the concept label and their links. In the context of physics, it is therefore important for the linking of these concepts to be sequenced in a manner that will not cause confusion, alternative conceptions or other kinds of challenges as concepts are developing.

There has been an increase in research studies on the manner which learners reason as learning progresses. Recently the study of the learners' conceptions attributed the attention to the way learners learn, develop knowledge, or alter knowledge in a specific field. Guisasola *et al.* (2003:445) believed that previous knowledge, progression of learning, conceptual change and refinement were highly important for conceptual development and improvement. They further emphasised the constructivist model to improve knowledge and recommended that it be based on conceptual refinement to reconstruct and change unacceptable concepts and to refine knowledge during conceptual development.

4.3 CONCEPTUAL DEVELOPMENT

Conceptual development is a process whereby new concepts productively fit into learners' existing mental models (Redish, 1994:11). This requires that new content be clarified in terms of known concepts that are familiar to everyday life and contexts so that effective learning can take place. Everyday life situations can serve as starting points to build new and abstract or complex mental models and concepts during learning process (Lemmer, 2013). For effective conceptual development, one needs to comprehend relevant concepts and place it in the conceptual framework, for the knowledge to be understood and applied.

The conceptual development model of teaching emphasises effective learning to be supported and achieved through assimilation (Redish, 1994:9). Through assimilation, a new concept builds and fits into an existing mental model. New content should be merged with the existing one and be contextualised through analogies so that teaching is effective and learning takes place. Redish believed that the use of analogies for effective learning in the lower grades or even in the daily teaching instruction should be chosen for the construction of new knowledge and for more abstract and complex mental models as learners move to the higher grades. The use of models and analogies is a natural process that occurs spontaneously from early childhood. In order to understand a new concept, similarities are learned using a known concept. If something is not well understood in the process of learning, a learner can form new alternative models while trying to connect their experiential ideas to the correct science concepts encountered in the classroom. These are not

scientifically correct models that emanate from everyday experiences using quick and illogical deductions.

Gunter *et al.* (2007:4) stated that capturing and formalising concept development could be a challenge. They further stated that the conceptual development process should reach out to learners to embrace their concept evaluation and selection during learning. Obscuring and confusing information arise when learners' pre-conceptions differ and clash or conflict with scientific fact during concept development. With timeframes, teachers need to have different options, with the intention to ensure that all the necessities and inevitabilities are covered. Then again, learners need to acquire knowledge in an innovative way, by exploring as broad a set of concepts as possible. According to Gunter *et al.* (2007:4), conceptual development can be explained in three main stages as outlined as follows:

- The first step is problem definition, where learners' preconceived conceptions are holistically deduced as difficulties and challenges to address. These challenges and difficulties are broken down into simpler sub-challenges, captured and documented to make a preliminary decision.
- The second one is concept generation, where solutions are investigated separately for each individual sub-problem, engaging internal and external investigative processes. Ideas are also discovered by teachers, using different tools to generate effective results and answers to the problem. Pictures, images and resolution are then joined and co-operated, combined and structured and lastly be selected to come up with thorough resolutions. Sub solutions to the sub-challenges are then consolidated to form complete resolution.
- The third stage of conceptual development was concept selection, where different concepts and alternative thoughts (outcomes) that were generated, are scrutinised and evaluated to proficiently accomplish improved conception.

Throughout the learning process, concepts are essential and very important for conceptual development in physical sciences. In the teaching of physical sciences, the ultimate objective to be achieved by the teachers is to make learners understand the science concepts and to connect them to their everyday life situations (Novak, 2002:551). Learners must know how to build the physical sciences theory into a

comprehensible physics framework so that they can use these concepts in extensive and inclusive different ways and contexts. During the learning process and concept elaborations, alternative conceptions can form and the correct scientific information can be rejected. Concept elaborations occurs when the correct scientifically new concept forms and consequently a logical conceptual framework is constructed (Jensen, 2008:173).

4.4 TEACHING APPROACHES: TEACHING FOR LEARNING

According to Dijkstra *et al.* (1990), there are two major processes of teaching for learning, namely planning and execution. Teaching involves knowledge systems or skills for proper learning to take place. The first system is the lesson organisation knowledge system referred to as lesson planning skill. The second one is instruction knowledge, denoting the skills to clarify the material, to pass questions and to give feedback. Lastly is the knowledge of classroom management, meaning the skill to run a lesson smoothly. The teacher plays a big role in planning and execution of teaching for learning. There is a need to identify the scientific approach and a need to find relevant strategies to achieve objectives of the lesson (Dijkstra *et al.*, 1990).

Knapp and Glenn (1996) compared the teacher-centred approach and learner-centred approach. The teacher-centred approach implicates the introduction of the material and skills, giving exercises to rehearse the skills, cramming the information and then testing learners' ability to recall the information. On the other hand, the learner-centred approach involves learners in activities that demonstrate creativity and innovation, solve problems and try to find address their challenges. In that model of learning and teaching, the teachers serve as mentors, coaches and resource persons. Teaching can then be perceived as a way of managing the learning process. It is a way of giving opportunities to learners to produce relatively permanent change through the commitment of knowledge's and skills presented by the teacher (Sharma, 2008).

In the following sub-sections, the traditional teacher-centred approach is discussed, followed by the constructivist learner-centred approach, then the categories of teaching approaches.

4.4.1 Traditional teacher-centred approach

The traditional approach to teaching is teacher-centred. The teacher-centred approach emphasises the teacher providing information to the learners. Learners are likely to be passive and reactive as instructed by the teacher (Kotoka, 2012).

Traditional teaching of physical sciences has been seen as a transmission process, whereby knowledge is transferred from the educator to the learner. The educator is an active teacher while the learner is a passive receiver of information. The educator and the textbook are the only sources of information. This information is absorbed by the learner and sequenced and incorporated in the same order as presented in the textbook and by the teacher. This is referred to as transmission learning, a product of rote learning. Rote learning and memorisation are all it takes for the learners to succeed through traditional teaching since no understanding of content is emphasised. The approach is only aimed at enabling learners to remember the information to succeed in assessments, with no emphasis on acquisition of constructive understanding and learning. No problem-solving skills or logic reasoning of facts and content are emphasised (Jacob, 1982:262). The teacher-centred approach and rote learning may be ineffective to stimulate learning, and retain pre-conceived knowledge and alternative conceptions. Learners may hold onto these incorrect preconceptions, particularly when a teacher centred approach is used (Ramnarain & Kiribige, 2010:10). Wood (2008) cited disadvantages of the teacher-centred method as stated below:

Disadvantages:

- Learners struggle to understand the objectives of the topics.
- The fundamental and central learning objectives such as communication and information literacy skills cannot be learned since they are generally quiet and only listening.
- The learners are not involved or active in the learning process all the time.
- The teacher is the only one who is active and only those special ones who are determined to learn, will learn.
- There is no co-operative learning among the learners and learning is not collaborative.

Effective teaching requires that learners participate actively, be allowed to exercise and connect the instruction to their pre-conceived or existing knowledge and that traditional teaching be discouraged.

4.4.2 Learner-centred teaching approach

A learner-centred approach emphasises that teaching be moved away from the transmission method of teaching, where the teacher will be the only active person in the class (Huba & Freed, 2000). Teachers must not be put as the active means and learners as passive vessels, but the learning space would rather be where new knowledge is formed and moulded through interaction, discussion of thoughts, deliberations, information flow and collaboration. Kahl and Venette (2010) emphasise that the focus should be shifted from teachers to learners where learners will be leading the discussions and learning process.

Learners should construct knowledge through collecting and simplifying information and incorporating it with different skills such as, practical, communication, critical thinking and problem-solving. The emphasis should be on the effective use of skill to address issues and problems arising during learning and from every day-life observation. The teacher's part should be to facilitate and to assist the learning process, while the learner is actively involved and both the teacher and learners evaluate learning together. The ethos of learning processes should be collaborative, supportive and collective learning effort to allow both the teacher and learners to learn together. These are positive advantages that support the learner-centred approach (Huba & Freed, 2000).

Kotoka (2012) in his research also supported the learner centred approach and reported more than the anticipated knowledge retention in the learner-centred and interactive method. He valued the learner-centred methods to be exciting as it reflects the interest of learners, for instance in the use of simulations. Even though the learner-centred view is supported by Kotoka in his study, he said there were limitations as well. Sullivan, Gnesdilow, Puntambekar and Kim, (2017) indicated limitations of the learner-centred approach that they can be time-consuming and not suitable for large classes. Although engagement strategies seem to impact positively on learning, the use of new methods can retard conceptual development and distract

students from the intended concept learning (Molefe, Lemmer & Smit, 2005). For example, modern strategies such as inquiry require a variety of process skills that the participants may not have mastered yet. However, simultaneous learning of different process skills together with the content can thus have a negative effect on progressive development of conceptual understanding if implemented incorrectly.

The learner centred approach success, can be achieved by using interactive teaching strategies such as PHET simulations, practical activities, models, cooperative learning and thought-provoking visual aids (Huba & Freed, 2000).

4.4.3 Sub-categories of teaching approaches

Trigwell (2004:419) conducted a qualitatively study on different ways of learning as an approach to teaching. He studied the variation of different teaching approaches to teaching and other aspects such as different situation and context in teaching. He studied the connections between different teaching and learning approaches. The study used a valid and reliable relational instrument to measure ways teachers see and approach their teaching. The implication of the research outcome was that teachers' focal point was on the different aspects of their teaching experiences and understandings of their situation and then related that to their teaching approaches.

Trigwell (2004:413) characterised these learning outcomes of these different approaches into five different categories. He described these categories as the outcome space of processes of learning concepts and approaches to teaching relevance. These characteristics are the dissimilarities between the outcomes approach and were outlined as follows:

Approach A: Teaching strategy whereby knowledge is transferred or transmitted from the educator to the learner.

Approach B: A teacher-focused strategy with the aim that learners obtain the knowledge,

Approach C: A teacher learner interaction strategy with the aim that learners obtain knowledge

Approach D: The strategy focuses on learners developing their own conceptions

Approach E: A strategy focuses on learners changing their conceptions, a learner-focussed approach.

These approaches ranged from transmission teaching and learning of content of the physical sciences, to the ones helping the learners to change their conceptions of the unacceptable preconceptions. The extremes of the strategies were both teacher and learner focused. He focussed more on these two extremes, the conceptual change/learner-focused approach and the transmission/teacher-focused approach (approach A and E). The presumption was that conceptual change (approach A) to teaching was directed to a worth quality learning and to greater teaching fulfilment than the transmission teaching approach. Approach 'A' (transmission teaching and learning) was highly discouraged as it does not meet the demands of physical sciences as a practical subject, as opposed to the extreme approach E. Trigwell *et al.*, (1999) as reported by Trigwell indicated that teacher-focused approaches was associated to learners' reproduction patterns. The other research outcomes showed that with approach E, learners achieved a meaningful and a deeper approach to learning (Trigwell, 2004:415-419).

Approach E assists learners to change their pre-conceptions and alternative conceptions to construct the correct scientific one. The teacher focal point is the learners' performance during the teaching and learning process. Learners must reconstruct their knowledge to construct new correct scientific conceptions. It is an effective learner centred approach that requires learners to take part actively and allow them to connect new concepts to their pre-conceived or existing knowledge. The learner centred approach considered learners' experiences and pre-knowledge. He indicated that learners perceive knowledge through conceptualisation and understanding of their diverse experiences around them and then retain it.

The other outcome of Trigwell study indicated contextual factors as well. The indication was that there were systematic relations of the way teachers teach and the quality of their learners' learning. The outcome of his study of the approaches to teaching and learning were perceived to be contextual and that the strategies implemented by teachers may vary in different context. He indicated that studies do not undoubtedly define the context, or do not emphasise different contextual factors in their studies. Sometimes research studies do not survey relations between the

target variables such as numbers in class, or even commitment of the target group. He indicated that the bearing of the relations was still unclear at the time he was doing research, but believed that the varying aspects of the teaching situation may assist to improve learning. According to Trigwell (2004:416-419), teachers who recognise that their workload is appropriate and that the level of learners' academic performance is good, are likely to choose approach A. He further pointed out that if the numbers are small and classes not overcrowded, teachers usually gain control over what is taught, and are more likely to adopt a conceptual change approach to teaching as well. When teachers feel that there is no real commitment to learner learning in their department, and that they struggle to conceptualise what is taught, teachers are more likely to implement Transmission approach (Trigwell, 2004:414-419).

4.5 CONCEPTUAL DEVELOPMENT TEACHING METHODS

Woolfolk (2010:476) indicated two central features of conceptual development methods in teaching. Firstly, is the teachers' commitment in making sure that the learners understand what is taught, without rushing to cover the syllabi and secondly, that each learner individually participate by making connections between the newly learned concepts and their existing knowledge.

While Woolfolk (2010:476) focussed on the central features when teaching for conceptual development, Bagno and Eylon (1997:726) perceive the central aspects related to concept development to be the structure of knowledge, the understanding of the core subject knowledge and the connection of conceptual understanding to its applications. Usually, challenges around these central aspects are affected by prior knowledge and or alternative conceptions. For learners to part with their alternative conceptions, they need to experience something that challenges the way they think to create a chance to absorb new content. Learners ought to be convinced that the scientific description and clarifications are better than theirs (Ramnarain & Kiribige, 2010:10). Bagno and Eylon (1997) emphasised that the correct scientific knowledge components of the learners' pre-conceived knowledge must be established to be used as a means of constructing scientific knowledge by means of a conceptual refinement method.

4.5.1 Conceptual refinement

Conceptual refinement is an approach that starts with learners' prior knowledge (Dekkers & Thijs, 1998; Hammer, 2000). Productive existing knowledge elements (also called resources) are to be refined in a constructive way for conceptual development of scientific knowledge. Dekkers & Thijs (1998) applied norms of the constructivist learning approach and the information processing approach in conceptual refinement instruction. Conceptual refinement instruction is a bottom-up strategy that develops learners' pre-conceived knowledge to scientific knowledge (Hammer, 2000; Redish, 2004). Consequently, one can use conceptual refinement strategy to logically sequence the subject matter to constructively develop scientific concepts using learners' existing experiential knowledge as starting point. Teachers need to guide the learners throughout the learning process to enable them to understand everyday life experiences and to expand concepts into a sound and consistent framework of knowledge (Scherr & Redish, 2005:41).

The conceptual refinement model is one of the didactical models used for learning physical sciences (Lemmer, 2011). According to this model, learners' pre-conceived knowledge is modified and advanced to the correct theoretical and scientifically accepted science knowledge. In the design of a teaching sequence, conceptual refinement aids in the selection and structuring of the activities to develop knowledge. The first activity link is the learners' experiential knowledge from which the scientific knowledge can be constructed. The intended scientific concepts, principles or law are generalised from a wide variety of contexts, after which they are formalised. Conceptual refinement and variation can consequently be used to bring together a sequence of activities that constructively prevent or bridge learners' content gaps (Lemmer, 2011).

Interactive teaching strategies that can be applied for conceptual development are simulations and practical work, as argued in the following section.

4.6 INTERACTIVE TEACHING STRATEGIES FOR CONCEPTUAL DEVELOPMENT

Conceptual development is a process whereby scientific concepts effectively fit into learners' pre-conceived or existing knowledge (Bagno & Eylon, 1997; Lemmer, 2011). This process requires relevant or scientific strategies that would challenge pre-conceived ideas that are scientifically incorrect and build on learners' acceptable but incomplete knowledge. Botha and Seroto (2010:96-98) pointed out scaffolding as one of the scientific teaching strategies. Scaffolding gives emphasis to the part that the teacher has to play to give support to learners in order to take them through to the next level of understanding. It bears a resemblance of structures to provide the learning of new content that would have not been gained or accessed on an individual basis, or that would have been hard to comprehend on their own. Scaffolds are gradually lessened as learners develop and learn to pay attention to the relevant aspects in investigation activities, to plan and control their investigations. The approach affords learners the opportunity to build on prior knowledge and to construct newly gained knowledge.

It has been well-established by science education research that interactive engagement courses are generally more successful at fostering learner learning than traditional teaching (Hake, 1998:64). In the opinion of Kotoka (2012), learners in classes taught with reformed interactive methods perform better on measures of conceptual understanding than their peers experiencing traditional instructional practices. Practical work and computer simulations are two interactive engagement strategies that may advance conceptual development (Chen *et al.*, 2012; Koponen & Mäntylä, 2006).

4.6.1 Practical work

Practical work plays a significant part in education and it is so vital and fundamental that almost all the textbooks point out that, physical sciences is a practical subject. Practically investigating the theories of physical sciences is very much critical to acquire physical sciences knowledge and to conceptualise it. Practical work is designed with the intention that they can be perceived as the actual and factual recognition of model systems. This permits an absolute and thorough interpretation of concepts and theory to which they are connected (Koponen & Mäntylä, 2006).

Ramnaraind and Kibirige (2010:2) classified practical work in terms of either the intended outcomes or its form. Outcomes may relate to content knowledge or process skills. Practical work outcomes are to assist the learners to identify and recognize phenomena to become conversant and knowledgeable with them. Furthermore, it assists learners to learn facts, concepts, relationships and theories. Process outcomes entail, amongst others, the handling of apparatus, performing of measurements, collecting and interpreting of data and compiling of reports.

Botha and Seroto (2010: 98-99) categorised experiments into three, and that are introductory experiments, illustrative experiments and investigative experiments. The teacher can use demonstrations to focus the learners' attention on a particular phenomenon and acquaint them with enquiry procedures such as observations and explanations. Accurate observation is an important skill to acquire information during investigations (Botha & Seroto, 2010:98; Trowbridge et al., 2004:199). Observations were perceived as an account of how an observer experience and understand the observed phenomenon. They state that observations are characterized by learners' knowledge, skills, interest and motivation. Therefore, the making of observations is essential in learners' construction and verification of knowledge. Scientific explanations of the observations are dependent on theory. Learners should learn to reflect on the information obtained from the observations in terms of the scientific knowledge to form scientific explanations (Hakkarian and Ahtee, 2010:167).

Mhlongo (2010) defines practical work as; *“a set of instructions that learners follow to verify a certain concept or law”*. Physics teachers strive to give a representation of physical sciences theories to their learners by making use of hands-on practical work

(Koponen & Mäntylä, 2006). To accomplish that, learners must set up the apparatus and follow the practical procedures to execute the experiments. In the experiment, theory is perceived as the efficient and successful arrangement and a way of organisation of dependencies exposed by practical work. An experiment is regarded as a simplification of facts and played a vital role in the history of physical sciences, and its legacy is still distinct. In teaching physics, the experiments give a genuine and a valid representation of the arrangement of information and the processes involved in producing it, as it contains itself with ease for the constructive way of teaching and learning.

The advantage of focussing on the execution of experiments is that the process logically generates systematic and efficient practical outcomes and conclusions can be deduced to support the learned theories. Physics teachers do not only have to provide deeply or detailed organised content knowledge, but also a comprehensive way of how the content knowledge is produced (Etkina *et al.*, 2002; May & Etkina, 2002). However, teachers' comprehension of concepts needs to be restructured such that the knowledge they convey in the classroom is relevant, appropriate and applicable for learning physics. For this changes and restructuring, methods that incorporate practical work, such as practical demonstration, has validated proper understanding and effective knowledge improvement (Bagno & Eylon, 2000; Van Heuvelen, 1991; Reif, 1987, 1995).

Practical work has long played a vital role in science education. There are rich benefits that accrue from using real experiments (TL), mainly, its potential to be an important medium for introducing learners to central conceptual and procedural knowledge and skills in science (Bybee *et al.*, 2008). 2000). Practical work provides real world experiences, but measurement errors and time consumption of data processing can retard learning of underlying principles. Demonstrations usually involve observation and verification of knowledge. Still, it may also be used as an experiment if a question is asked of which the answer is not immediately apparent. Although students may be more engaged (Sullivan *et al.*, 2017) and learn a variety of process skills in individual experimentation, demonstrations have its place in science learning (Bybee *et al.*, 2008). Reasons that justify the use of demonstrations include that it lowers cost, reduces time, requires less apparatus and can prevent damage or

students' use of hazardous apparatus. Another important reason is that the teacher can direct students' thinking and stimulate their analytical and synthetic reasoning processes (Bybee *et al.*, 2008).

Sullivan *et al.* (2017:1) stated that research on the use of practical work to support learners' learning has identified various conflicting outcomes. Unanswered questions remained on how practical work may impact learners' learning and for which content knowledge and contexts may be most effective (Sullivan *et al.*, 2017:1). At times learners may focus on learning the practical skill if an individual experiment is done, and miss learning for conceptual development. The new factor, learning of skills, may retard conceptual development because of focus being directed to the skills rather than concepts.

On the other hand, during a demonstration, learners' attention can be focused by the instructor on the development of concepts as they are observing the practical demonstration and responding to questions. In a demonstration, a teacher has a better indication of the learners' thinking process and can do much to stimulate them to be more critical and synthetic in their reasoning (Bybee *et al.*, 2008). Through demonstration lessons, learners observe for conceptual understanding while at the same time they learn by observations and question how to execute the experiment and how to manipulate the apparatus (Rodger *et al.*, 2008:236).

School assessment task must be designed in such a way that learners are tested on their scientific inquiry skills to gather information. The skills that must be tested include planning, executing, observation, comprehending, synthesising, conclusions and generalising. Practical work need to assess these skills at different cognitive levels and focus on critical thinking, problem solving and scientific reasoning in different scientific contexts. These skills are not only crucial to science learning and teaching, but also essential for application in everyday life situations and technology (DoE: 2009a:11).

Hofstein and Lunetta (1991:125) state that both practical work and computer simulations can enable the learners to work with models of reality, to tackle and to solve problems, observe effects and make decisions. According to Zacharia (2007:221) learning outcomes do not significantly change once real experiments

(RE) is replaced by virtual experiment (VE). It is therefore imperative to research also on resources such as computer simulations to establish its impact for constructivist learning approach. The next paragraphs give summative discussions on computer simulations.

4.6.2 Computer simulations

Computer simulation is “a program that contains a model of a system (natural or artificial, e.g. equipment) or a process” (Hofstein & Lunetta, 1991:125). Simulations imitate imaginary situations and circumstances that may seem unreal and present them through models and in a way which allows the user to interact with it. Interacting with an instructional simulation could enable learners to understand systems, processes or phenomena. The use of these programs can impact in ways that were not previously possible (Akpan, 2001). As opposed to traditional methods, the use of computer simulations in physical sciences classes has the advantages that learners can systematically and thoroughly explore theoretical and imaginary circumstances, by interacting with simplified versions of practical investigations and phenomena to find real answers in a practical situation without stress (Van Berkum & De Jong, 1991).

Kotoka (2012) emphasised that computer simulations could impact optimally in the learning and teaching of physical sciences because learners find it difficult to visualise most of the concepts such as in electrodynamics. He investigated the impact of a learner-centred approach that made use of PHET simulations and the outcomes tested his hypothesis correct. The major finding of his study was that simulations might be the answer for the teachers to teach challenging topics and content that is difficult to figure out. His contribution to literature provided proof that if simulations can be used jointly with a learner-centred approach for teaching and learning, it might have a strong impact on the understanding of physical sciences concepts. Kotoka also suggested that PHET simulations could be used to support the traditional approach to teaching. Computer simulations can be incorporated in normal traditional teaching methods to make physical sciences learning easier and it saves time used on the chalk board. He further argued that computer simulations enhance constructivist learning Norstrom (2011:1) agreed that simulations and

hands-on activities can lead to suitable results in abstract engineering and science courses.

The use of simulations has a major impact as a complementary tool for conceptual-refinement, established by the incorporation of technology and suitable instructional strategies (Chen *et al.*, 2012:1). Difficult concepts can be clarified, alternative conceptions corrected and scientific concepts refined to improve conceptual development.

In the learning area of electrodynamics, the use of computer simulations is important, as they can make it possible to present and to portray dynamic images and give a picture of difficult scientific situations and theories for the learners to comprehend. Dori and Belcher (2004) applied computer software to teach physical sciences in order to increase learners' conceptual understanding of the subject. The strategy was used to help learners visualise conceptual models and to comprehend electromagnetic phenomena. They contended that using visualisations helped learners to understand these phenomena and to see imaginary things like field lines.

Technology such as computer simulations has vastly impacted teaching and learning in a positive way (Dori & Belcher, 2004; Kotoka, 2012). Learners have turned out to be more involved during learning processes with the use of computer simulations. With the help of the teacher and the computer simulations, learners predict, observe, discuss and explain concepts with ease. In addition, the simulations give learners opportunity to imagine and create in their mind pictures that enable them to comprehend and understand many concepts. It clarifies concepts and diagrams and it draws learners' attention to what is presented and make them more active in class. It promotes class-control and brings progress, stimulation, excitement and enthusiasm. Learners are able to create imaginary concepts in their mind through observations during the lessons and it makes concepts such as magnetic field lines real. Simulations can illustrate and demonstrate movements of multifaceted part process, especially complex applications of physical sciences concepts, thereby describing and illustrating functions that would not be possible and feasible to separate and observe independently, thus clarifying concepts.

A study conducted by Collins (1991:28) investigated the impact of computer simulations in teaching and learning. He remarked that we are living in a world where most work is becoming computer-based and that the use of technology for learning cannot be ignored. He further alluded that a learner would retain visual information effortlessly and with less difficulty than verbal information used in normal traditional teaching. Access to computer simulations and visual resources or equipment may possibly expand learners' ability to comprehend and to learn, mostly in the case of the learners having difficulty to understand from books and teachers. At the time of the study, diverse Information Communication Technology applications that exist, seek to arouse learners' interest and stimulates active engagement.

Agina (2003) added several advantages of computer simulations. Learners gain knowledge quicker and improve their attitude positively towards learning when engaged in a lesson that involves computer simulations due to interaction of the learner with the learning processes and the resources. Interactive learning allows learners to pay attention, arouse their interest and strengthens their skills because it is interesting, stimulating and fun to explore. It persuades learners to revisit the program over and over, accomplishing continued practice. Computer technology can further present hazardous and precarious experiments without the risks or danger. They protect and promote safety as they cannot be carried out in the classroom. Simulations can show the impracticable in a manner that is real. Learners interact with the content and as a result they are likely to incorporate the knowledge and skills concerned with understanding (Agina, 2003).

While computer simulations give exciting and stimulating opportunities for learning, learners turn out to be more inspired and encouraged to learn physical sciences (Agina, 2003). Frustration because of experiments that fail due to wrong procedures or techniques is eliminated. Practical work is observed by all the learners because of the interactive methods of simulations that clarify concepts and improve knowledge retention. Computer simulations are reliable and consistent as all the learners observe and learn similar knowledge and skills. With computer simulations, learners get instant feedback or response and this improves and enhances their practical and scientific capabilities and skills. Computer simulations usually compel content

software designers to structure or organise learning and teaching materials more effectively, with the result that it advantages learning.

Stavy (2008:54) reported three main points of importance of working with simulations. The first point was that it helps to visualise the abstract concepts and demonstrate the content knowledge in a concrete and real way. The second point indicated was that it enables learners to work on their own time, to play the animation repeatedly as much as they would want, while controlling the rate at which the simulation or software runs. The last point was that the activities contribute to the diversification of the lessons by providing immediate feedback. The anticipated observations are confirmed by successive proceedings and actions of the animations; when the learners recognise and comprehend how these phenomena unfold. The step by step of observations of simulations and how the process is caused lead to concept refinement and understanding of a phenomenon.

In the field of physical sciences and topics such as electrodynamics, animations and simulations are critical. They allow and represent pictures that are vibrant and animate exiting images. They can assist and clarify relationships among concepts that are sometimes even difficult for teachers to understand (Dori & Belcher, 2004). According to Dori and Belcher (2004), they used computer simulation and practical work to refine and to improve teachers' content knowledge of physical sciences. In trying to improve teachers' knowledge and increasing their logical understanding of electrodynamics, meaningful learning was of key importance. In their study, the methodology was designed to assist teachers to expand their scientific knowledge and to enhance better insight and understanding of induction and electromagnetic processes through computer simulations.

The study of Zacharia (2007:121) pointed out that during the past decade there have been many positive claims around the potential of computer simulations to improve physical sciences laboratory teaching and learning. However, the outcomes of learning do not significantly change when a real experiment (RE) is substituted by a virtual experiment (VE), they can both achieve the same objectives. Computer simulations demonstrate a positive impact on learners' conceptual understanding, but there are limitations as well. It deprives learners of skills that encompass hands-on handling of physical materials that is important for science learning. Non-

traditional labs therefore acquire knowledge in a fundamentally different way than scientists originally worked (Zacharia, 2007:121-122). Lai and Kritsonis as cited by Kotoka, (2012) further expatiate disadvantages of computer simulations as bulleted below:

- Cost: The first disadvantage is high cost needed to buy them and learners can only be exposed in schools that can afford them. However, the schools that cannot afford computer technology can use one computer with a data projector for lessons presentation, thereby saving costs.
- Isolation: Another drawback is that it can create communication breakdown in class and lack of interaction between teachers and learners. Contrary to that, the teacher can develop a teaching sequence in a manner that will allow interaction with the computer and the teacher. The teacher could facilitate the lesson by incorporating computer technology in a normal traditional lesson. Learners can also be grouped to talk about what is observed and learned in the computer lesson and be given the opportunity to report verbally to the teacher and the class.
- Knowledge: It is crucial that the computer user be in a position to operate and to have a basic understanding of computers before they can be used to support in learning and teaching.
- Classroom management: Even though the computer technology approach support learner-centred teaching which is more encouraged because of its effectiveness over the teacher-centred method, (Veermans *et al.*, 2006), the level to which the teacher can manage the learners in class create limitations.

If the support of discovery learning within a computer technology application is not enough, then the learners will have problems adapting to experimental designs, interpretation of data and innovation and creativity (De Jong & Van Joolingen, 1998). Insufficient guidance will obviously lead to a decline of the effectiveness of inquiry learning (Van Berkum & De Jong, 1991). West (2009) states that the expectations of computer technology are grounded on the learners' working independently, but then the teachers' assistance during learning process is of outmost importance. The method encourages active learning, while at the same time learners enjoy and learn.

Feedback on the correctness of ideas occurs as the instructor probes understanding of concepts during observations of phenomena (West, 2009).

Simulating many different physical phenomena is an area of intense research which holds much promise for teachers' knowledge improvement in the field of physics teaching and for conceptual development (West, 2006). It is believed that, by presenting teachers with correct visual representations of physical phenomena, knowledge can be actively reconstructed and improved with more correct conceptions.

Computer technology and simulations can save time for the teachers and give time, interest and concentration to the learners. The setting of experimental variables can be manipulated with ease, allowing the identification of all the features of the experiment. Computer technology creates a representation of real and non-real situations or background and put the learner in an active mode of the learning process. It creates a greater scope of visualisation, design and control of environment for learners. The computer is operated and directed by the learner and the learning process revolves around the instructions to investigate and to unfold the learning processes and to stimulate understanding (Ogbom, 1998). The next two paragraphs summarise two possible examples of simulations to be used in this study.

4.6.2.1 *Physics education technology (PhET) project*

The Physics Education Technology (PhET) venture creates helpful and practical animations and simulations for teaching and learning of practical subjects such as physical sciences and can be accessed freely from the website (<http://phet.colorado.edu>). The program is developed for educators and learners to represent and demonstrate phenomenon in science and technology. In the process of the development of this software, they were tested by the researchers on learners and teachers in the classroom situations and the results were analysed to check the impact and effectiveness of them (Beer, 2010).

4.6.2.2 *You-tube simulations*

The You-tube software also provides helpful and practical simulations and animations for teaching and learning of practical subjects. The computer technology from the You-tube application software is also available to be downloaded online ([www. http://you-tube.com](http://you-tube.com)). It is also one of the valuable and useful teaching resources that effectively support teaching and learning of practical subjects. It has soft-wares that are designed specifically for secondary science curriculum and syllabus and cover all the topics in the FET curriculum. The software provides intense and stimulating learning tools that can present abstract concepts that seem not real and represent them in a real manner. The quality and effectiveness is such that it engages learners and is thought provoking to stimulate understanding.

4.6.3 TRADITIONAL LABORATORY (TL) VERSUS NON-TRADITIONAL LABORATORY (NTL)

Practical work in this study refers to hands-on or real experimentation by controlling equipment or apparatus, which according to Brinson (2015:219-220) is referred to as traditional laboratory (TL) and real experiment (RE) according to Zacharia (2007:123). Furthermore, simulation in this study is referred to as experiments that are not real because they are simulated on computers. Simulations are referred to as the non-traditional laboratory (NTL) set-up as stated by Zacharia, and virtual experiment (VE) as stated by Zacharia. Simulations are experiment that are presented in the non-traditional manner and virtually observed in a computer.

Brinson (2015:219-220) compiled an evaluation of comparative studies regarding the efficiency of and perceptions about traditional laboratories (TL) versus non-traditional laboratories (NTL). While TLs entail hands-on or real experimentation by controlling equipment or apparatus, the required NTL set-up is not real, but simulated on computers. Zacharia, (2007:123) also presented the findings of his study and pointed out that the outcomes of real experiment (RE) and virtual experiment (VE) are not substantially different. Brinson articulated that no consensus existed among researchers regarding the effectiveness of each lab type relative to one another, and that the outcomes varied from study to study. Instances where NTL simulations brought about a higher level of conceptual understanding, researchers would raise a

concern of physical skills or handling of apparatus and chemical equipment being compromised. When TL and NTL methods were compared with each other for electric circuits, Zacharia and De Jong (2014) also found similar effect on learners' understanding.

According to the reviews of Brinson (2015) as well as Ma and Nickerson (2006), some research findings support traditional hands-on labs while others argue for non-traditional labs (including computer simulations). NTL are perceived either as hindrances or helpful to learning (Brinson, 2015). Learners with advanced pre conceived knowledge were identified to be benefitting more from simulations. The statement accounts that higher levels of complexity need an explicit representation like in a virtual experiment. The statement endorses that teachers should be mindful of the use of NTL. Equally, it warns of the overuse of NTL as it might prevent learners from being able to self-construct abstract concepts (Brinson, 2015:219-220).

The deductions made in Brinson's (2015) review on the content knowledge achieved in TL and NTL laboratory types, was the consequence of data obtained in different science disciplines. On ground of his findings, Brinson (2015:230) advocated research into blending TL and NTL. Zacharia (2007) reported higher conceptual understanding on electric circuits when TL and NTL methods are combined in comparison to TL methods only. Toth, Morrow and Ludvico (2009) confirmed that blending improve learners' knowledge. Characteristics of TL and NTL complement each other, for example, TL make students aware of measurement errors in real experiments, while NTL provides visual support in learning.

4.7 TOOLS FOR LEARNING ABSTRACT CONCEPTS: MODELS AND ANALOGIES

Models and analogies are often used in teaching to explain difficult concepts (Redish, 1994:11). These can be handy to explain some features of reality, but must be used with care in the classroom. Hence it is vital to create a sound structure for the course around well-selected concepts and contexts. According to Redish (1994:11), concept development for learning is a challenge and can be difficult to achieve as it is very difficult to change pre-conceived mental models that are prevailing. To change learners' incorrect preconceived science knowledge, the new knowledge ought to be understandable and plausible, should intensely contradict the alternative conceptions and need to be suitable and valuable.

4.8 SUMMARY

This study wanted to contribute to the teaching and learning of physical sciences, specifically electrodynamics, by allowing the learning process to be realistic, motivational and practical for the teachers and eventually for their learners. This problem was addressed by integrating both simulations and practical work with theory, to provide learning support that will not restrict the learners' possibilities of freely exploring. Concept refinement was a methods adopted to achieve conceptual development in a teaching sequence using practical work and computer simulations as strategies to effectively learn electrodynamics. This sequence broadly follows the constructivist approach to the learning and teaching of electrodynamics.

Based on the literature review above, the questions were aroused that directed this study, namely what impact will interactive methods have on teachers' pre-conceived incorrect scientific knowledge and in the reconstruction of such? Conceptual refinement was adopted as teaching methods in this study, with the use of simulations and practical work as strategies for conceptual development in electrodynamics. The implementation of these teaching methods and strategies are discussed in the subsequent chapter (Chapter 5) that outlines the research methodology and design followed in this study.

CHAPTER 5: RESEARCH DESIGN AND RESEARCH METHODOLOGY

5.1 INTRODUCTION

The previous chapters (Chapter 2-4) reviewed and examined other researcher's views or studies from different perspectives and informed the design and methodology of this study. These chapters presented current issues on electrodynamics and the teaching and learning of electrodynamics and provided a framework for the empirical study. The literature review gave a broad perspective of studies conducted on electrodynamics and created an opportunity to understand areas that still needed attention as well as provided a framework for the empirical study (refer to Figure 1.1 of Chapter 1). Chapter 2 of the literature study explored and reviewed relevant content knowledge and focused on the key concepts and the fundamental principles of electrodynamics. The purpose of the review was for the researcher to gain more content knowledge in order to positively respond to the research demands, to create a platform to confidently impart knowledge and deal with teachers' content gaps and to contribute into the improvement of their content knowledge during the empirical study. Chapter 3 provided a literature study of challenges encountered in the learning of electrodynamics. This chapter revealed the roots of alternative conception and gave perspective to the possible challenges that were phasing this study. Chapter 4 reviewed and examined instructional models, strategies and approaches that were relevant for the teaching of physics for conceptual development. The research design, methodology and the procedure that was followed in the empirical section of this study are discussed below.

This chapter entails the design and methodologies that were used and followed to answer the research questions and to achieve the objectives of the study, as stated in section 1.6 of Chapter 1. Chapter 5 outlines the roles played by the researcher and sampling of the empirical study as discussed in section 5.2.4. In section 5.2.4 to 5.2.5, the chapter outlines the data collection procedure and the data collection instruments. Section 5.2.5 explains how the instrument has been constructed as well as its validity and reliability. Furthermore, section 5.2.7 to 5.2.8 report on how the data has been collected and analysed. Finally, the ethical aspects were discussed in section 5.3.

5.2 RESEARCH DESIGN AND METHODOLOGY

This empirical study combined both qualitative (QUAL) and quantitative (quan) forms of research. A combination of both approaches was used since the strength of one added to the strength of the other (Creswell & Plano, 2007; Creswell, 2009:4). This design, usually referred to as mixed method research, allows the researcher to investigate various approaches for collecting and analysing data rather than subscribing to only one method. In this study, a mixed method approach was used as the procedure for collecting, analysing and mixing quantitative and qualitative data to address the research problem completely.

5.2.1 Overview of the empirical study

The intended outcome of this research was to investigate the impact of a teaching sequence using simulations and experiments on physical sciences teachers' conceptual development of electrodynamics. It was deemed necessary and important to first know the challenges and obstacles that participants experienced with the learning and understanding of electrodynamics. A three-day workshop (intervention) was conducted with the anticipation of determining and addressing the challenges that prohibited the understanding of electrodynamics.

5.2.1.1 *Teaching strategy*

Both the control group and the experimental group were instructed in teacher-centered ways in order to control the multitude of possible variables that may affect differences in learning gains. The sequence of presentation of the content was also exactly the same for the experimental and control groups, i.e. the same slides were used. The only difference between the two groups was the inclusion of experiments and simulations with the experimental group. Throughout the presentation, practical demonstrations and simulations were presented as the design directed them to the attainment of the identified concepts and principles to be achieved.

Factors such as content and context in a teaching sequence, can impact negatively in concept learning, if not properly managed (Sullivan *et al.*, 2017). With reference to content affecting the teaching sequence in this study, electrodynamics is an abstract

topic that requires sound pre-knowledge, understanding and basic explanations. The context was that the teacher participants were familiar with teacher-centred strategies, they use them in their classrooms and sadly, they lacked practical skills. According to Sullivan *et al.* (2017:1) simultaneous learning of different process skills together with the content can impact negatively on progressive development of conceptual understanding, which was a concern in this study.

In this study, the researcher adopted an illustrative experiment type with focus on content outcomes. The category was described as experiments done to illustrate or confirm already known facts, concepts or principles. When learners still lack content knowledge or have content gaps in a particular topic, the teacher can still demonstrate the facts practically to illustrate or confirm already known concepts or to familiarize the idea to the learners (Botha & Seroto, 2010:98-99; Ramnarian & Kibirige, 2010:2-3)

This study entailed a demonstration technic of activities where learners observe unexpected results that may be contradictory to their normal experience or expectations. Learners used the basic skills of predicting the outcomes, observing the results of an experiment, and giving an explanation or inference (Lemmer & du Toit, 2010:40-45).

Brinson (2015:221) encouraged investigation that combines TL and NTL in order to support greater learning achievement. In this study, there was a need for both TL and NTL to provide teachers with frequent opportunities for feedback, reflection and modification of their ideas. Both labs were used complementary, so that their strong points could be capitalized towards more effective learning.

In order to enhance engagement in the intervention, the teacher-centered instruction for both groups focused on conceptual development (Approach B of Trigell) (Trigell, 2004:143). The participants attentively concentrated on the presentation and reacted during the intervention by giving the instructor indications that they understand, asked questions or reiterated what is discussed and explained (refer to appendix J). The instructor could immediately attend to the students' difficulties as they occurred.

The control group participants were prompted to predict the outcome of the experiment before they observed it, and thereafter explained their observations. The

discussion of each step of a demonstration as it was performed, was advantages for directing the students' thinking about what they observed and giving attention to learning difficulties as they occurred. For example, the participants' struggling to connect the concepts of flux and EMF (refer to section 6.5.1), could have been addressed as it came to the fore. The participants were also given the opportunity to be hands-on where possible. They were alternately afforded the opportunity to perform an experiment for the group where possible, under the supervision of the researcher.

5.2.1.2 *Teaching sequence*

One of the objectives of the study was to design and investigate the impact of a teaching sequence such that it enhances the conceptual understanding of electrodynamics among physical sciences teachers. The rationale in this study was to present a teaching sequence that requires instructional support and mediation via sound curriculum and practical strategies. In order to achieve these objectives, the design followed the historical development and complemented it with the sequence of concepts and the practical work as prescribed in the FET syllabus. The historical development touched all the related conceptual domain of electrodynamics (refer to 2.2 of chapter 2) and leaving very limited content gaps. Thus the teaching sequence was designed to holistically embrace almost all the related concepts and in a manner that was expected to enhance conceptual development for knowledge improvement. The concepts were sequenced in a logic presentation (refer to appendix G), and practical work (appendix E) and or computer simulations (appendix I) was integrated within the lesson presentation with discussions during the intervention.

The theoretical framework that guided the design of the teaching sequence was constructivism, according to which knowledge was gradually build up by combining new knowledge with existing knowledge (refer to appendix G and H). The sequence comprised of 6 subdivisions. Apart from subdivision 1 that deals with the most basic concepts, each subdivision focused on building up of concepts towards an electromagnetic application. The sequence unfolded as follows: basic knowledge (subdivision 1), electromagnets (subdivision 2), electric motor (subdivision 3), electromagnetic induction (subdivision 4), the generator (subdivision 5) and transformers (subdivision 6). Each subdivision gradually proceeds from relevant

underlying concepts, explanation of the appliance, and ends with discussion of its use in everyday life. The structure was as follows:

Subdivision 1: Basic knowledge about forces, fields and moving charges.

Differences in sources and interactions of magnetic and electric fields are emphasized for two reasons:

- It is foundational to understanding electrodynamics phenomena
- In order to prevent concept confusion, a learning obstacle amongst South African teachers (Hekkenberg, Lemmer & Dekkers, 2015).

Subdivision 2: Electromagnets

Refinement of knowledge from the electric field around a single charge to a straight conductor, current loop to a solenoid culminated in the electromagnet.

Subdivision 3: The electric motor

The working of an electric motor is based on the understanding of interaction between two magnetic fields. An external field between bar magnets interacts with the field around a current of charges, causing a force on the conductor perpendicular to the external field.

Subdivision 4: Induction

Conceptual understanding of induction is mainly that a changing magnetic field can produce a current in a closed circuit. It is the reverse of that of the electric motor and the process is called electromagnetic induction. The concept of electric flux and Faraday's law are also core concepts in electrodynamics.

Subdivision 5: The generator

The principle underlying the generator applies to the application of induction. To generate electricity, the change in magnetic flux must cut across a closed circuit

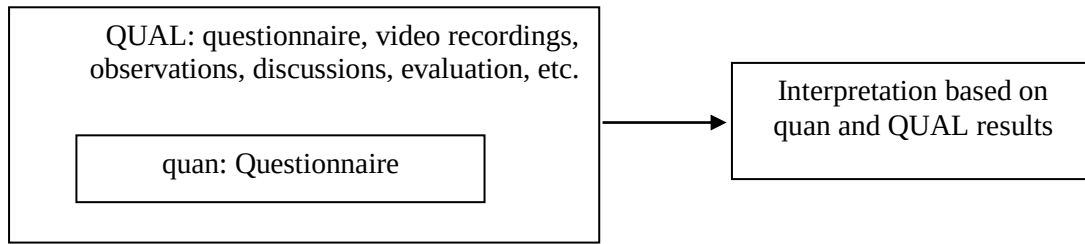
Subdivision 6: The transformer

The transformer applies both the principles underlying electric motors and generators. To produce a current in the secondary, AC current must be used in the primary. Therefore, this part commences with AC electricity and associated concepts of RMS value and mutual induction.

5.2.2 Research design

The purpose of this research was supported by a pragmatic world view and mixed method (QUAN-qual) for data collection and analysis were used, with more emphasis on the qualitative method. The embedded mixed method design was selected and implemented to answer secondary questions that were related to the main research question stated in section 1.4.2 Chapter 1. The reason for choosing this approach was to enhance the qualitative study with a supplemental quantitative data set. The relationship among variables were examined, measured and subsequently data was analysed using statistical procedures, while the approach enabled the researcher to focus on conceptual development and the importance of rendering the complexity of a situation (Creswell, 2009:4).

Quantitative data were used to inform the discussions of the participants' past and present content knowledge and challenges that prohibited the understanding of electrodynamics. A survey was conducted by means of a questionnaire (see Appendix E). Surveys offered versatile, credible information about a large number of teachers (North West physical sciences teachers), that can be inferred from responses obtained from a small group of teachers (refer to population and sampling) and allowed generalisation across the population (McMillan & Schumacher, 2010:4, 236). In this study, the quantitative data was embedded within the qualitative experimental design as illustrated in Figure 5.1 below.



Figur

e 5. 1: Embedded mixed method design (Maree, 2012:276)

5.2.3 Study population and sample

The North-West Province is made up of four education districts and each district consists of Circuit Offices. The researcher sampled the physical sciences teachers of the two clusters (Madikwe and Elands cluster) falling under Kgetleng circuit of Ngaka Modiri Molema district in North West Province (South Africa). The teachers of Kgetleng circuit in Ngaka Modiri Molema district were sampled for this study. The Elands cluster, consisting of sixteen teachers, formed the experiment group and the Madikwe cluster, consisting of fifteen teachers, formed the control group. Both groups attended the workshop for three days in the same venue, one after the other for two consecutive weeks. The participants were selected purposefully to enable the researcher to best understand the research problem.

5.2.4 Data collection procedure

The activities that were done during the empirical study were prepared by the researcher to enable appropriate and successful data collection process.

5.2.4.1 Quantitative data procedure

The instrument that was used to collect the quantitative data was designed. The same questionnaire (Appendix E) was used as a pre- and a post-test and was administered under the supervision of the researcher. The pre-test was administered three weeks before the intervention to allow the researcher enough time to analyse the participants' responses and to design an effective intervention instrument. The post test was administered to both groups immediately after the intervention to make

fair comparison of the impact. The data was collected in the same manner from both groups.

5.2.4.2 *Qualitative data procedure*

Qualitative data was collected by means of a questionnaire, which was used as a pre- and post-test. The last section of the instrument contained open ended questions that required explanations and reasoning from participant. The researcher additionally developed a reporting template that was used by individual participants to reflect on their challenges prior to the commencement of the workshop (intervention).

For the purpose of intervention, a three-day workshop was conducted to provide more of qualitative data collection. The researcher conducted three-day content workshops, while collecting data. During that time, the researcher implemented a teaching sequence and evaluated its effectiveness. A procedure to laboratory learning, pointed out by Brinson (2015:230) as “blended” or “hybrid” approach, was adopted in this study. Traditional laboratory work using apparatus and non-traditional computer-based simulations were integrated in the constructivist teaching sequence. The ultimately goal in this study was to take advantage of the potentials of both methods of experimentation in order to make the most of the effectiveness of laboratory work (Zacharia, 2007:122, 129). The activities that were designed for implementation during the intervention process were discussed in section 5.2.1.2 above.

The researcher developed a lesson presentation (refer to Appendix G) that hyperlinked the simulations attached as Appendix I and that were applicable to the research topic. The simulations used during the intervention were downloaded from the PHET simulations and you-tube.

The researcher also identified the relevant experiments, at least one per concept and developed a work book (Appendix H) that was used by participants for experiments in the workshop. The work book was well designed and included topics and detailed instructions, and also provided spaces for illustrations, sketches and diagrams. The workbook was developed to be used in conjunction with the practical demonstration

to record observations and findings effectively (Botha & Seroto, 2010:98-99). Each participant received an experiment work-book which was used during the execution of the experiments in the intervention lesson.

This study was thus a systematic physics education research that involved the development and implementation of a new instructional sequence based on experiments and simulations that can provide participants a more effective learning environment. The use of simulations and practical work has a common impact as a complementary tool for conceptual development (Chen *et al.*, 2012:1). Some experiments were demonstrated, and others were projected as simulations. Simulations were complementing practical demonstrations to address issues like time, and also provide correct, clear and accurate outcomes to achieve the main objective. With the help of both practical and the computer simulations, learners predict, observe, discuss and qualitatively explain concepts.

During the intervention, the lesson presentation was facilitated and conducted by the researcher in order to personally collect the first-hand information and undistorted data, with the use of simulations and practical demonstration complementing each other for conceptual development of electrodynamics. Qualitative data was collected during the workshop (intervention process). The data was collected by means of video records that were transcribed by the researcher (refer to Appendix J).

The researcher also designed an evaluation form for the participants to evaluate and criticise the teaching sequence that was used in this study (refer to Appendix F). The questions were designed to get an honest opinion from the participant about the intervention process and its impact in learning. The evaluation form gave an honest feedback from the participants, which provided qualitative data. The diagrammatical illustration below provides an overview of the data collection procedure followed in this study.

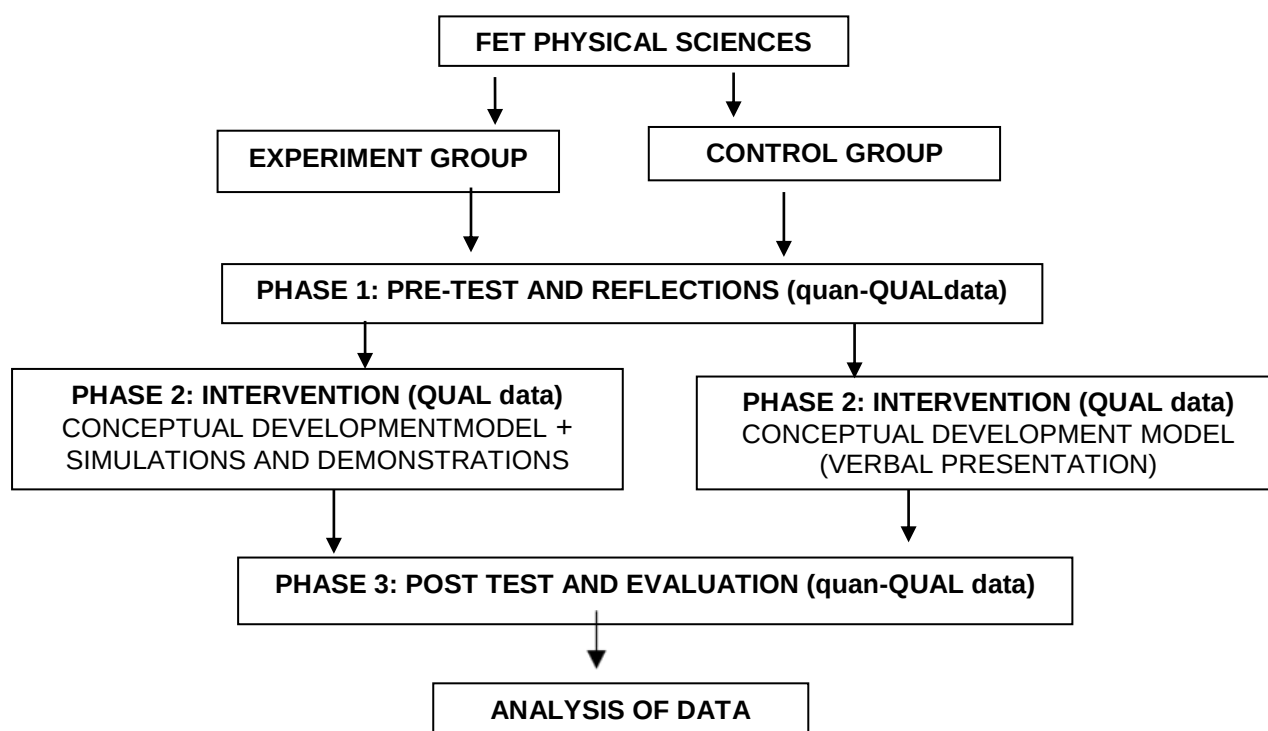


Figure 5.2: Overview of data collection procedure

5.2.5 Data collection instrument

The questionnaire was divided into two sections, namely section A and B and spaces were provided for answers. Section A of the questionnaire consisted of 20 closed items (items 1 – 20), which intended to gather the biographical profile of the participants.

Section B of the questionnaire consisted of content knowledge questions based on electrodynamics informed by the FET (physical sciences) syllabus (DBE, 2011) and related to the research topic. Section B consisted of three parts that required quantitative and qualitative responses from the participants about their existing conceptual knowledge of electrodynamics. Section B was designed to identify concepts or parts of the topic that were challenging, while at the same time answering research question 1.4.2.1. Part one and two consisted of fifteen (15) items, five (5) from basic concepts of electrodynamics and ten (10) from the electromagnetic induction, the core knowledge of electrodynamics. Part three of

section B was qualitatively structured and is discussed under the qualitative data discussion. Part one and two of Section B is described below.

Part one of section B focused on the basic concepts of electrodynamics (which covered and or combined electricity and magnetism questions). The part probed into the participants' existing and basic knowledge of electrodynamics / electromagnetic induction. Part 1 aimed to identify the challenges that participants might have had to understand the cause of the difficulties to the understanding of electromagnetic induction (refer to objective 1.3.2.1). Challenges in this study referred to pre-knowledge gaps, alternative conceptions, confusions and difficulties. Part one consisted of five items, and required the participants to tick correct answer(s) from the options provided. Three questions required more than one answers, thereby increasing the total of correct answers from five (5) to ten (10). Part two of section B consisted of ten multiple choice items and four options were provided to choose one correct answer. The part tested the understanding of concepts in electrodynamics, with the core knowledge area being electromagnetic induction and its processes.

5.2.5.1 *Reliability and validity of the measuring instrument*

Developing a questionnaire or test is imperative in research, because it impacts directly on the type of data that are likely to be produced. It is therefore very important that, prior the empirical research study, questions such as whether the research instruments cover what the researcher wants to establish, have to be cautiously considered by the researcher. The questions with regard to validity and reliability of research instruments are very important (Gay & Airasian, 2003:141), hence the questionnaire that was developed in this study had to be tested for validity and reliability.

In this study, the instrument intended to establish the content knowledge of the participants before and after intervention, thereby measuring knowledge improvement effected by the teaching sequence. Creswell (2009:233) explains reliability as; "the extent to which the measuring instrument is repeatable and consistent". In this study, the instrument was repeated as a pre-test-post-test, meaning the same questionnaire was used twice for both experimental and control

groups. Each group of participants wrote the same test before and after intervention and allocation of scores remained as they were.

For the instruments and content validity purposes; the questionnaire was given to three experts in physical sciences education research. The intention was to check and validate the appropriateness of the content of the instrument. These three experts were given the structured questionnaire to read, to answer and to make valuable suggestions on the extent which the instrument covered the relevant content of the research topic (electrodynamics). A statistical consultant at the North-West University was also asked to review the questionnaire for its validity and reliability (Creswell, 2009:235).

Furthermore, the pilot study was also done prior to the empirical study to ensure the content validity of the questionnaire. A pilot sample was chosen, tested and used to validate the instruments used in this study. The sample used as pilot in this study comprised of in-service part-time teachers perusing a physical sciences Advanced Certificate in Education (ACE) programme at the North-West University. Physical sciences teachers in the sample group were well-qualified in physics education. This made this pilot sample appropriate to be used for piloting the pre-post-test (questionnaire). The group was used to answer the questionnaire to enable the researcher to check for the reliability of the test before the empirical study.

5.2.6 Research method

The researcher collected two types of data that complimented each other and produced a broad and complete analysis of the research study. Participants' written reports (reflections and evaluation form), questionnaires (pre- and post-test) and video-recorded activities (presentation, experiments, simulating and discussions) were analysed. Part 1 and 2 of the questionnaire were further expanded to create new data that categorised the individual items and made constructs that could be analysed to validate the broad understanding of concepts. The new data created construct and correlation between items in electro-dynamics and were divided into four categories, namely: Moving charge producing magnetic field; Lenz's law; Induction; Magnetic fields (B) interaction. This would mean that, in addition to the

quantitative data that was collected in this study, categorised quantitative data was extracted in the process.

Collection of data occurred in three phases, before intervention, during intervention and after intervention. Both quantitative and qualitative data were covered in the questionnaire and more of the qualitative data was collected from the video recordings, participants' reflections and evaluation form. All the participants started by writing a pre-test during the first phase, thereafter the teaching sequence (intervention) were executed. Immediately after the interventions, post-test was administered to both experiment and control groups.

Phase one of the empirical studies as discussed in section 1.5.3.1 captured mixed methods data collection by means of a questionnaire and participants reflection. In this phase data was collected to determine the participants' existing knowledge and the challenges. The intent of the quan-QUAL data collection in this phase was to probe and to establish the participants' challenges that were barriers to the understanding of electrodynamics.

The second phase took place during the intervention and the whole process and data were captured using a video recorder (Refer to section 1.5.3.2) as indicated above. A video recording captured the impact of simulations and experiments for the reconstruction and improvement of knowledge during conceptual development of electrodynamics. The video recordings captured enabled the researcher to identify the alternative conceptions during discussions and reasoning that evolved during the conceptual development throughout the intervention process.

As expanded in section 1.5.3.3, the third phase mostly required qualitative data, except for the post-test questionnaire sections that required quantitative data and only one section of the questionnaire, Part 3 of section B, required qualitative data. The same questionnaire that was used as the pre-test was administered immediately after the intervention as a post-test, to establish content knowledge learning gain and the impact of the intervention. The other data was collected by the evaluation form that required an honest opinion or descriptive feedback of the participants on the impact of the intervention and its processes. The evaluation form allowed the participants to evaluate and criticise the teaching sequence that was used in this

study (refer to Appendix F). The data provided comment and pointers on the impact of the teaching sequence for conceptual development and knowledge improvement. All these qualified the study to be a qualitative-quantitative research.

The next paragraph gives the description of the quantitative data collection and how the data was analysed.

5.2.7 Quantitative data collection and analysis

5.2.7.1 *Quantitative data collection*

The quantitative part of this study was conducted by means of an experimental method plan. According to Creswell (2009), an experimental design in quantitative research is used to test the impact of intervention on an outcome whilst the researcher controls all other factors that might influence the outcome. The intention for quantitative data collection in this study was to compare the content learning gain due to the interventions (Creswell, 2009:115, 208, 229) and to validate the impact of teaching sequence using the questionnaire as a measuring instrument (Hake, 1998:1).

Part one and two of section B of the questionnaire were designed to collect data quantitatively. The questionnaire was administered as the pre-test three weeks before the intervention workshop. The same instrument was administered as a post-test immediately after intervention lessons of the experiment and the control group. The experiment group and the control group all wrote the same pre-test. The two groups were then exposed to two different methods of teaching electrodynamics as an intervention. Immediately after the intervention, the same questionnaire that was administered as a pre-test was used again as a post-test.

5.2.7.2 *Quantitative analysis*

Meltzer (2002:1261) states that, to assess learning, it is necessary to have a measure that reflects the transition between knowledge at different states and that has maximum dependence on instruction, with minimum dependence on learners' pre-instruction states. In this study, such a measure was provided by calculation of average normalised learning gains from the pre- and post-test results as indicator of

the effectiveness of an intervention (Hake, 1998; Meltzer, 2002:1259-1266). The pre-test and post-test of each group were captured and analysed statistically by the statistical consultant and thereafter finalised by the researcher.

- **Statistical analysis**

The quantitative data was captured by Statistical Consultation Services of the NWU (Potchefstroom Campus). Participants' responses to Section A (biographical details) that was captured, provided the information of the participants and their schools. The statistical data captured was presented as frequencies based on the backgrounds, teaching experiences and contextual factors of all the participants. The frequency of the biographical data indicated a great deal of similarities among the participants of the experiment and the control group. That means the similarities of the participants were more than the differences.

Items of Section B of the pre-test (part one and two), were also captured by the statistical consultant and presented as frequencies as well. Post-test results were also statistically captured as it had been done with the pre-test. The interpretation of data from statistical consultation services gave the outline to the researcher to set a user-friendly frequency table for the research.

The statistical consultant further used the data to create a construct to allow factor analysis. The Cronbach Alpha (CA) values that were determined did not qualify the process due to the low CA values. A new plan was executed. A confirmatory factor analysis was again statistically calculated to measure the validity of the item tested using the Cronbach's Alpha coefficient. For the new calculation, the two items, referred to as out-shooters, were removed and the Cronbach Alpha validated making constructs. Concepts were categorised to create constructs, (refer to section 5.2.6 and 5.2.7.2.3). In the next paragraph, the quantitative analysis of Part one and two of Section B of the questionnaire is discussed.

- **Item analysis**

The frequency data from statistics was interpreted by the researcher and presented as percentages (see Chapter 6). From the frequency table, two sets of analyses were done, namely item analysis of the pre-test and the post-test.

For pre-test analysis, both groups of participants were taken as one population and data was then interpreted to analyse pre-knowledge of all the participants before intervention. At that stage, the biographical analysis indicated that both groups were at the same level of understanding the concepts, hence the analysis of one population. Pre-test analysis was done per item and focused on items that were underperformed by the majority. The purpose was to capture and to interpret common alternative conceptions, content gaps, confusions and any challenge in terms of content knowledge before intervention.

Part one of section B tested the basic concepts and the analysis established the basic concepts that were still missing and challenging the participants. During the analysis, the researcher was interested in the interpretation of the answers, irrespective of the correctness or the incorrectness of the answer. The missing answers were excluded in the analysis while the correct answers were bolded (see Table 6.2 of Chapter 6). The margin of 50% was taken as an underperformance, with less than 30% as poor performance. Underperformance and or poor performance in this study meant insufficient knowledge, content gaps, confusions, misconnection and any other challenge that contribute to underperformance. The margin was based on the fact that participants were physical sciences teachers teaching the topic to FET phase and the research topic was in the syllabus across all FET grades taught by the participants.

To establish the knowledge gained in this study, item analysis of the post-test was done the same way as the pre-test to allow a comparison of the knowledge improvement of the two groups after intervention. The same process of analysis of the results obtained from the pre-test was repeated in a post-test. Interpretation of data was done per item to analyse and to compare the knowledge gained per item after intervention. The average normalised learning gain was calculated (Hake, 2002:3) and the means were also calculated in order to answer the main research question as stated in section 1.4.1 above.

The learning gain comparison was done bearing in mind what Melzter (2002:1260) emphasised. According to Meltzer (2002), practically all previously published studies on the physics course performance leave open the question of how and whether such performance may be related to conceptual understanding of physics. He further

emphasised that the question of how to measure learning gain is not simple and is subject to many methodological difficulties. Although various factors may be correlated with learners' performance in physics, the connections may not be a straight evidence that there is a contributory connection between the two.

Creswell (2009:11) argues that a pre-test and post-test method provides a valid measurement of the impact of an intervention. Since the number of participants in this study was small (N=31), average normalised learning gains were calculated from the results of the pre- and post-tests to evaluate the effectiveness of the interventions with the experimental and control groups. The average learning gain was calculated for the quantitative part of the questionnaire. According to Hake (1998:64-74), if ' $\langle g \rangle$ -value' was smaller than 0.05, then it was regarded as statistically and practically significant. Average normalised learning gains take differences in pre-test scores of two groups into account (Hake, 1998:64-74).

- **Factor analysis**

Following the item analysis, the factor analysis was done to make a construct of items of similar concepts and to establish the correlation between items in electrodynamics. The participants' answers were interpreted and analysed in accordance with the categories stated in the procedure. A comparison of constructs in different categories was analysed to establish consistency in the knowledge category, as well as reasons for inconsistency in answering question testing the same knowledge concepts. Consistency in construct referred to the essence of reliability in answering items within a specific category, that is, if one item was correctly answered, the other within the same category was to be correctly answered as well. The results needed to find the participants' understanding and adequacy of knowledge in different concept categories (Guisasola *et al.*, 2004:445-447).

5.2.8 Qualitative data collection and analysis

5.2.8.1 Qualitative data collection

According to Locke *et al.* (1987), as cited in Creswell (2009:194), the rationale behind qualitative research is to understand a specific social situation, event, group, role or interaction. In this study, the research approach helped to probe deeper in the participants' experiences, pre-conceived knowledge, difficulties and any other challenges during the conceptual development of electrodynamics. Creswell (2009:175) states that qualitative researchers do not use one source of data, but various data sources. Hence in this study, data was collected qualitatively using a questionnaire, written reports and video recordings.

The first part, of the qualitative data was collected through the questionnaire covered under part three of section B, was collected using an instrument and consisted of open ended questions that required explanations and reasoning. This part covered applications of electromagnetic induction (electrodynamics). Only four open ended questions were asked for the following reasons: to avoid unclear or useless responses and to avoid the difficulty of scoring open-ended questions or what is usually referred to as free response questions (Gay & Airasian, 2003).

The second part of the qualitative data was collected through participants' written reports, followed by discussions of their reports. This process was administered on both the control and experimental groups and was video recorded. A template was developed for use at the beginning of the workshop, and the participants were asked to reflect in writing on concepts that they thought were difficult for them and the learners to understand electromagnetism. The participants were asked to write down the concepts that were of a challenge to them and those that were difficult to explain to learners, and to give reasons as to why they thought so. The written reports (reflections) were then read out, then followed by group discussions. The researcher facilitated and led the group discussion based on the reports or reflections. The template was tabulated in two columns consisting of two main headings, as illustrated in Table 5.1, to set a proper platform and to probe on the participants' pre-knowledge and challenges.

Table 5.1: Reflections of challenging concepts in Electrodynamics

Learners: Difficult concepts of Electromagnetism (electrodynamics)	Teachers: Difficult concepts of electromagnetism (electrodynamics)
1.	1.
2.	2.

The big part (third part) of the qualitative data was collected during a three-day content workshop that was arranged and facilitated by the researcher and was video recorded. For the content workshop (intervention), the researcher prepared the following: three-day presentation (Annexure G), practical workbook (Annexure H), workshop evaluation form (Annexure F) and report template for reflections. The researcher facilitated the workshop and conducted experiments on the process. The former grade 12 physics learner was approached to video record the workshop process and activities. This process was administered on the experimental group only and was video recorded. However, the control group also went through a three-day workshop, but theirs excluded the use of simulations and practical work and created ample time for clarification of concepts and more detailed explanations. The workshop was also conducted by the researcher. The total of six days was utilised by the researcher to conduct two workshops for the control and experiment group.

The last part (fourth part) of the qualitative data was collected in the form of a report, where the evaluation form was provided after the intervention. The questionnaire kind of a report was provided to evaluate the impact of a teaching sequence and methods that were used during the intervention. In the evaluation form, all participants (control and experiment) were asked to reflect in writing on the challenges that they had before the workshop and the ways that sufficiently addressed these challenges. Participants also evaluated (the advantages and limitations) the sequence used in the intervention. Thereafter, the comments were taken for further discussions and clarity. Comments were based on individual evaluation of the teaching sequence (impact of simulations and experiments) in order to interpret and make sense of how the whole intervention process unfolded. This process was administered on both control and experimental groups and was video recorded.

5.2.8.2 *Qualitative analysis*

Open ended responses, part 3 of section B of the questionnaire (refer to Appendix E) and video recordings are qualitatively analysed in 6.5.1 and 6.5.2 of Chapter 6.

An analysis of open ended responses (part 3) was done to obtain a deeper understanding of reasoning and usage of concepts and possible alternative conceptions and confusions. The results of the pre and post-tests of both groups were used for comparison and to evaluate knowledge improvement (refer to Table 6.5 and 6.8 of Chapter 6).

The data of the video recordings that was shot during the intervention was qualitatively analysed to provide a deeper understanding of the research problem. Video-taped activities were reviewed repeatedly and coded during the process (Creswell, 2009:199). Participants' written reports were also coded and compared with data obtained in the videos. The quantitative analysis was supported by the qualitative analysis. The researcher identified challenges, alternative conceptions, confusions and gaps in the video that was recorded during intervention and compared with the quantitative analysis.

The last part of the data was the completion of the evaluation form that was provided at the end of the three-day workshop. Participants' written reports in the evaluation questionnaire were analysed to get feedback of the entire workshop. The analysis of the evaluation form provided feedback on the teaching sequences that were used during the intervention.

5.3 ETHICAL ASPECTS OF THE RESEARCH

The permission to conduct the research was granted by the North-West University (NWU) Faculty of Education Sciences after permission was granted by the North-West Department of Education. The permission enabled the researcher to conduct research in Kgetleng circuit office of the North-West province of South Africa in Ngaka Modiri Molema District (see Appendices A and B respectively). These are requirements before any research can be carried out with the Department of Education to ensure that the research done by the researcher complies with the protection of the rights of the subjects as well as to ensure that due process is followed. One of the responsibilities of the researcher to the participants in this study was to ensure that they were protected from any victimisation, information distortions or any other forms of practices that might infringe on their rights as participants in the study. The researcher was guided by the fact that participants in a research study have the right to be informed about the aims, purposes and likely publication of findings of the research and of potential consequences for participants and to give their informed consent (see appendix B) before participating in the research. For this reason, the researcher met with the participants to be involved in the study and explained to them what would be required of them during the research. It was also emphasised that participation in the study was voluntary and that nobody would be victimised in any way, as stated in their consent letters. They could also withdraw from the research at any time, if they wanted to.

Permission to conduct research was requested from the North-West Education Department as well as from the teachers who were participating (see Appendices A, B and C). Circulars were also sent to all the secondary schools in Kgetleng circuit, inviting them to attend the workshop. The study was relevant for the context explained in this paragraph and was conducted in the form of a series of content workshops, where data was collected. Evidence of the workshop included signed registers, a circular that was sent to school about the workshop and material used during the workshop, all attached as Appendices D and E. Data that was collected was submitted by the researcher to the supervisors as evidence that the content examined was trustworthy and credible based on the evidence. The supervisor and the statistical services indicated that the data must be kept safe and that it was the

responsibility of the researcher to make sure the material was safely secured. There was no disconfirming evidence that contradicted the established evidence (Creswell & Plano Clark, 2007:135).

5.4SUMMARY

This chapter described the research design; the methodology used and offered the discussion of procedures that were followed in carrying out the study. The subsequent chapter (Chapter 6) presents the results and interpretations that emanated from the analysis of the empirical part of the research.

CHAPTER 6: INTERPRETATION AND ANALYSIS OF RESULTS

6.1 INTRODUCTION

In this chapter, the quantitative and qualitative results (data and its analysis) emanating from the research are presented and discussed. The analysis helped to answer the research questions which guided this research as stated in 1.4, and the conclusions regarding the research questions were then drawn in Chapter 7.

Two groups of participants (the experimental and control groups of 16 and 15 participants respectively) were exposed to two different teaching sequences for conceptual development. Their biographical profiles are given in section 6.2. Both groups answered the questionnaire attached as Appendix E that was administered as both pre- and post-test before and after the interventions. The data collected and the analysis thereof (sections 6.3 and 6.4) were to establish knowledge improvement or knowledge gained by the two groups who were exposed to the two different teaching sequences for conceptual development. The statistical results were captured and used to determine whether the post-test scores of the two groups were significantly different to answer the research question.

In addition to the questionnaire, qualitative data was collected by means of participants' reflections before the intervention as well as video recordings of the learning process during the intervention and that was followed by participants' evaluations. These results are discussed in section 6.5.

The quantitative and qualitative data results obtained in this study supplemented each other and integrated interpretations are given for a broader and deeper understanding of the research problem in sections 6.6 to 6.8.

6.2 BIOGRAPHICAL PROFILE: SECTION A OF THE QUESTIONNAIRE

Section A of the questionnaire obtained the biographical profile of the two groups of physical sciences teachers (participants) who participated in this study. Thirty-one participants completed the questionnaire and their biographical details are presented in Table 6.1 below. The profiles of the control group (15 participants) and the experimental group (16 participants) are shown in the Table.

Table 6.1: Educators biographic information

PROFILE	OPTIONS	CONTROL (15)		EXPERIMENT (16)	
		15	%	16	%
Gender	Males	5	33.3	9	56.3
	Females	10	66.7	7	43.8
Age	20-30	4	26.7	5	31.3
	31-40	0	0.0	7	43.8
	41-50	6	40.0	3	20.0
	50-60	5	33.3	0	0.0
Overall experience	1-5	4	26.7	6	37.5
	6-10	1	6.7	4	25.0
	11-20	2	13.3	5	31.3
	21-30+	9	60.0	1	6.3
Physics teaching experience	1-5	12	80.0	10	62.5
	6-10	1	6.7	3	18.8
	11-20	2	13.3	3	18.8
	21-30+	0	0.0	0	0.0
Overall qualification	Diploma	3	13.3	3	18.8
	Degree	10	66.7	8	50.0
	B.Ed. (Hons) degree	0	0.0	5	31.3
	M Ed degree	1	6.7	0	0.0
	PhD degree	1	6.7	0	0.0
Physics qualification	Diploma	3	13.3	1	6.3
	Degree	10	66.7	5	31.3
	B.Ed. (Hons) degree	0	0	2	12.5
	M Ed degree	1	6.7	8	50.0
	PhD degree	1	6.7	0	0
Post Level	Teacher	13	86.7	12	75.0
	HOD	2	13.3	3	18.8
	Dep. Principal	0	0.0	1	6.3
	Principal	0	0.0	0	0.0
School location	Urban	5	35.7	1	6.3
	Rural	9	64.3	15	93.8
Electricity	Yes	15	100.0	16	100.0

	No	0	0.0	0	0.0
Water	Yes	13	86.7	15	93.8
	No	2	13.3	1	6.3
Grades taught	Grade 10	13	86.7	12	75.0
	Grade 11	13	86.7	12	75.0
	Grade 12	13	86.7	11	68.8
Total numbers taught	10-20	10	71.4	5	31.3
	21-30	1	7.1	4	25.0
	31-40	1	7.1	3	18.8
	41-50	1	7.1	2	12.5
	50-100	1	7.1	2	12.5
Laboratory	Yes	10	66.7	9	56.3
	No	5	33.3	7	43.8
Equipment/apparatus	Well-equipped	1	6.7	1	6.7
	Moderate/Few	7	46.7	7	43.8
	None	7	46.7	7	43.8
ICT software	Yes	11	73.3	7	43.8
	No	4	26.7	9	56.3
Computer avail at school	Yes	8	53.3	7	43.8
	No	7	46.7	9	56.3
Teaching using computer	Regularly	0	0.0	5	31.3
	Seldom	6	40.0	5	31.3
	Never	9	60.0	6	37.5
Do you own a computer	Yes	7	46.7	11	68.8
	No	8	53.3	5	31.3
Medium of instruction for teaching	English	14	93.3	11	73.3
	Afrikaans	0	0.0	3	20.0
	Alternate between	1	6.7	1	6.7
Medium of instruction for the majority of learners	Mother tongue	1	6.7	6	37.5
	2 nd Language	14	93.3	10	62.5
	3 rd Language	0	0.0	0	0.0

DISCUSSION OF BIOGRAPHICAL PROFILE

Gender: Almost the same number of female and male participants who taught physical sciences in the FET Band completed the questionnaire. In other words, no significant differences occurred between number of males and females, both from the experimental and control groups.

Age: The largest percentages of the participants (43.8%) from the experimental group were mature teachers (31 to 40 years old). The researcher observed that, due to shortage of science teachers, most matured teachers tended to move from deep rural areas that were far from town and transferred to the semi-rural ones closer to town. Contrary to that, the control group indicated that 0% teachers were in that age group (31 to 40 years). The older teachers (above 40 years) tended to prefer comfort zones and remained in those deep rural areas and did not transfer nearer to town. The control group cluster was the furthest from town and circuit office and a total of 73.3 % of teachers were above the age of 41.

Overall and physics teaching experience: Most of the participants had more than 5 years of teaching experience and could therefore be regarded as experienced teachers. Contrary to their overall experience, most had less than 5 years teaching experience in physical sciences in the FET Band and could therefore be regarded as teachers with inadequate experience of teaching the subject to learners in the particular band.

Qualification: Most of the participants held teaching degree qualifications. It could therefore be deduced that most participants were professionally qualified in terms of their qualifications. The majority of the participants from both groups held a qualification higher than a diploma in physical sciences (physics/chemistry). One can thus accept that most of the participants were adequately qualified to teach the subject to learners in the FET Band.

Position, school location, electricity and water: The majority of the participants were post-level one, indicating that they were not in management positions. Most of the schools were situated in rural areas. All the schools had electricity and most of the schools had running water

Grades taught and numbers taught: Almost all the participants were teaching in the FET band across grades 10 to 12 and the number of learners taught ranged mostly from 10 to 20, also indicating small numbers of learners doing physical sciences in the rural areas.

Laboratory and equipment/apparatus: Several schools (12) were still without laboratories, while 19 out of 31 (61.2 %) had laboratories that did not seem to be adequately equipped.

ICT software and computer availability: Less than 50 % (15 participants out of 31) indicated to have computers at their schools. Then 18 participants (58.1 %) had personal computers and 18 ICT-software, but most participants indicated that they never used those computers for physical sciences classes.

Medium of instruction for teaching and for learners: Most participants used English as the medium of instruction to teach physical sciences at their schools. English was the learners' second language, and their home language was Setswana or Afrikaans.

The following discussion in section 6.3 gives the analysis of the questionnaire written before the intervention. Quantitative data was obtained from parts 1 and 2 of section B of the questionnaire and is discussed in 6.3.1. Then the qualitative data, which covered part 3 of section B, plus the video recording data, are analysed in 6.3.2.

6.3 QUANTITATIVE ANALYSIS BEFORE INTERVENTION

One of the objectives of this study (refer to 1.3.2.1 of the Chapter 1) was to determine the participants' existing and basic knowledge of electrodynamics comprising of electromagnetic induction, applications thereof and underlying concepts in order to find the participants' knowledge gaps, alternative conceptions, confusions and other difficulties. Both groups of participants were taken as one population to analyse the pre-test. The demographic profiles support the assumption that all participants are physical sciences teachers with teaching experience and relevant qualifications.

Section 6.3.1 present the participants' responses based on Part 1 that was aimed at identifying their existing content knowledge.

6.3.1 Pre-test item analysis

Table 6.2 below gives the results per item of part 1 and 2 of section B of the questionnaire, (refer to Appendix E) for all the 31 participants and for individual groups (16 experimental and 15 controlled groups). Part 1 was aimed at identifying the pre-knowledge gaps that participants might have to understand the cause of the difficulties to the understanding of electrodynamics (refer to objective 1.3.2.1 of Chapter 1). Part 1 and 2 consisted of fifteen (15) items, five (5) from basic concepts underlying the research topic and ten (10) from the research topic. Three questions from the basic concepts had more than one answers, thereby bringing the total of possible answers to 20. In Table 6.2 the correct answers are in upper case and bolded in black. The missing values (meaning the participants were silent about their answers) are excluded in the table since the researcher wanted to interpret the answers provided.

Table 6.2: Pre-test item results

Question (#)	Option	Control		Experimental		All participants	
		# out of 15	%	# out of 16	%	# out of 31	%
1.1	a)	5	38.46	2	13.33	7	22.6
	b)	0	0	1	6.67	1	3.2
	c)	2	15.38	6	40	8	25.8
	D)	0	0	5	33.33	5	16.1
	e)	6	46.15	1	6.67	7	22.6
1.2	A)	8	57.14	11	68.75	19	61.3
	b)	4	28.57	3	18.75	7	22.6
	C)	9	64.29	5	31.25	14	45.2
	D)	1	7.14	1	6.25	2	6.5
	E)	2	14.29	7	43.75	9	29.0
	f)	0	100	2	12.5	2	6.5
1.3	A)	13	86.67	10	66.67	23	74.2
	b)	4	26.67	5	33.33	9	29.0
	c)	3	20	4	26.67	7	22.6

	d)	1	6.67	0	0	1	3.2
1.4	a)	1	7.69	3	23.08	4	12.9
	b)	4	30.77	3	23.08	7	22.6
	c)	4	30.77	2	15.38	6	19.4
	D)	4	30.77	5	38.46	9	29.0
1.5	a)	6	46.15	7	58.33	13	41.9
	b)	0	0	3	25	3	9.7
	c)	1	7.69	1	8.33	2	6.5
	D)	4	30.77	2	16.67	6	19.4
	e)	2	15.38	0	0	2	6.5
2.1	a)	5	38.46	8	53.33	13	41.9
	b)	0	0	1	6.67	1	3.2
	c)	2	15.38	1	6.67	3	9.7
	d)	6	46.15	5	33.33	11	35.5
2.2	a)	2	18.18	4	28.57	6	19.4
	B)	1	9.09	2	14.29	3	9.7
	c)	3	27.27	3	21.43	6	19.4
	d)	5	45.45	5	35.71	10	32.3
2.3	a)	5	35.71	3	20	8	25.8
	b)	3	21.43	1	6.67	4	12.9
	C)	4	28.57	9	60	13	41.9
	d)	2	14.29	2	13.33	4	12.9
2.4	a)	6	46.15	0	0	6	19.4
	b)	1	7.69	2	12.5	3	9.7
	C)	0	0	1	6.25	1	3.2
	d)	4	46.15	16	81.25	20	64.5
2.5	a)	2	15.38	4	25	6	19.4
	b)	9	69.23	3	56.25	12	38.7
	c)	1	7.69	0	0	1	3.2
	D)	1	7.69	3	18.75	4	12.9
2.6	A)	3	23.08	9	60	12	38.7
	b)	4	30.77	3	20	7	22.6
	c)	3	23.08	0	0	3	9.7
	d)	3	23.08	3	20	6	19.4
2.7	a)	0	0	0	0	0	0
	B)	11	84.62	7	50	18	58.1
	c)	0	0	2	14.29	2	6.5
	d)	2	15.38	5	35.71	7	22.6
2.8	A)	7	53.85	5	33.33	12	38.7

	b)	2	15.38	3	20	5	16.1
	c)	3	23.08	6	40	9	29.0
	d)	1	7.69	1	6.67	2	6.5
2.9	a)	4	28.57	0	0	4	12.9
	B)	1	7.14	10	71.43	11	35.5
	c)	0	0	2	14.29	2	65
	d)	9	7.69	2	14.29	11	35.5
2.10	a)	5	35.71	3	20	8	25.8
	b)	2	14.29	5	33.33	7	22.6
	C)	5	35.71	6	40	11	35.5
	d)	2	14.29	1	6.67	3	9.7

The results of Table 6.2 show that the control group participants outperformed the experimental group participants in five out of the 17 possible correct responses, while the experimental group participants achieved higher scores in six items. The two groups achieved with similar percentages in six other items. Although the pre-test results of the two groups differed, normalized learning gains take such differences into account, that is according to Melzter (2002:1260). Therefore, the interpretation of the results of Table 6.2 combined responses given by participants of both groups. The purpose of the combined analysis was to capture common alternative conceptions, content gaps and any challenge of the research topic (objective 1) among the physical sciences teachers. 50% was taken as the margin for performance and below 30% as poor performance. In Table 6.2, the correct options are indicated in capital letters, but those below 50 % are bolded, and then below 30 % still bolded capital letters but italic. The margin was chosen because the participants are physical sciences teachers teaching FET phase and the research topic being in the syllabus across all FET grades taught by the participants. Therefore, they were expected to obtain a minimum of 50 % in each question.

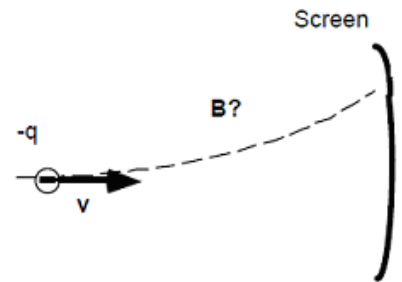
The results indicated that only three answers out of 20 were performed above the 50% margin. Ten answers were a way below the margin (below 30%), with seven answers still below the margin but above 30% (i.e. between 30% and 50%). The 50% would then mean underperformance in the item, meaning content gaps, confusions; alternative conceptions, etc. (refer to research question 1.4.2.1).

In the next paragraph, the pre-test results are analysed per item, with special focus on items that the majority got incorrect. Following the item analysis, the category analysis is discussed.

Pre-test item analysis for combined group

Item 1.1: *An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. What is the direction of this magnetic field?*

- a) *Towards the top of the page*
- b) *Towards the bottom of the page*
- c) *Into the page*
- d) *Out of the page*
- e) *The magnetic field is in the direction of the curved path.*



The results showed that only 16.1% applied the Lorentz force equation correctly for the given motion of the electron and consequently marked option (D) (i.e. out of the page). The 25.8% who chose option (c) (into the page) also knew that the magnetic force acted perpendicular to both the charge's velocity and the magnetic field, but probably applied the Lorentz force equation for a positive instead of a negative charge. A similar percentage (22.6%) of participants marked option (A), thinking that the magnetic field either followed the upwards curvature of the path.

Item 1.2: *Which of the options below cause a magnetic field?*

- a) *A magnet*
- b) *A charge at rest*
- c) *A moving charge*
- d) *A steady current*
- e) *A changing current*
- f) *A magnetic field*

Of the six options provided to the question, four were correct answers (A, C, D and E) and the other two were incorrect. The majority (61.3%) incorrectly thought that magnets were the only sources of magnetic fields (option A). Some (22.6%)

participants ticked option B showing that they confused magnetic and electric fields by saying a charge at rest can produce a magnetic field. The two options (a) and (b) were identified as alternative conceptions also indicated as alternative conceptions in Chapter 3 of the literature review (refer to alternative conception number four (4) and seven (7) of Table 3.1). The percentages obtained for the other three scientifically correct options were below the 50% margin with options D and E a way below the below 30% margin. These options (C, D and E) are discussed in more depth in the following paragraphs.

Item 1.2C: The results revealed that only 45.2% knew that a moving charge cause a magnetic field, although it is taught explicitly in the grade 11 curricula (refer to section 2.3 of Chapter 2). It seems as if they thought a magnet is the only object that can produce magnetic fields.

Item 1.2D: The results revealed that only 6.5% of participants knew that a steady current caused a magnetic field. Although this forms part of the FET syllabus, the item was the worst performed and can be regarded as a content gap.

Item 1.2E: The results revealed that 29.0% of the two groups understood that a change in current caused a change in magnetic field. This is one of the basic concepts of induction and the result supports the literature (refer to alternative conception number nine (9) of Table 3.1 of Chapter 3) that electromagnetic induction is a challenge to the learners.

Item 1.3: *Consider a compass, which points to the magnetic north pole of the earth. A number of objects are then brought near to the compass. Which can cause the compass needle to change direction?*

- a) *A bar magnet*
- b) *A large charge at rest*
- c) *An electric wire with a current*
- d) *None of these*

A compass is a good detector of magnetic fields because in the presence of one the needle (which is a small magnet) will rotate until it is oriented toward the magnetic

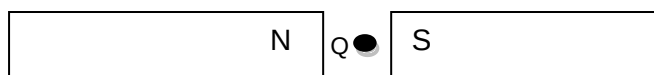
field. Two correct answers were thus provided to Item 1.3, namely the option of a bar magnet (option A) and the option of electric wire with current (option C), since these are sources of magnetic fields. A large percentage of the participants (74.2%) ticked option A (magnet) but only 22.6% indicated the second option (C) of current, which supports the results of Item 1.2 above. Most participants thus believed that only magnets and not electric current could produce magnetic fields.

1.4. A soft iron rod placed inside a current carrying solenoid

- a) *Increases the electric and magnetic field strength produced by the solenoid.*
- b) *Increases the electric field strength in the solenoid.*
- c) *Decreases the magnetic field strength produced by the solenoid*
- d) *Increases the magnetic field strength produced by the solenoid.*

Item 1.4d was performed below 30%. The results revealed that less than a quarter (23.0%) of the participants knew that a soft iron rod placed inside a current carrying solenoid (option D) increased the magnetic field strength produced by the solenoid. This is one of the items in which the correct percentage was below 30%. This difficulty might be due to lack of knowledge that the magnetic field is caused by a current in the wires of the solenoid. This deficiency was shown in the previous two items (1.2 and 1.3) and can thus be considered a content gap on which further knowledge cannot be built.

Item 1.5: *A positive charge Q is placed in a uniform magnetic field produced between two magnets.*



- a. *If stationary, the positive charge (Q) will be subjected to a magnetic force.*
- b. *If the positive charge (Q) is moving parallel to the uniform magnetic field (e.g. to the right in Figure 1 above) it will be subjected to a magnetic force.*
- c. *If the positive charge (Q) is moving parallel to the uniform magnetic field (e.g. to the left in Figure 1 above) it will be subjected to a magnetic force.*

- d. *If the positive charge (Q) is moving perpendicular to the uniform magnetic field (e.g. upward in Figure 1) it will be subjected to a magnetic force.*
- e. *If the positive charge (Q) is moving perpendicular to the uniform magnetic field (e.g. downward in Figure 1) it will be subjected to a magnetic force.*

The item tested if the participants understood when a charge was affected by an external magnetic field (B) and recognised that an electric field could not interact with a magnetic field. The results revealed that less than 30% of the participants understood that only magnetic fields could interact with each other and that a charge would not be subjected to the external magnetic field (B) if it was stationary or moving parallel to the magnetic field of the bar magnet. Two correct options were provided and both were poorly answered at 19.4% (option D) and 6.5% (option E) by the participants.

Items 2.1 to 2.10 of the questionnaire that was discussed above tested the basics of electrodynamics. The results indicated that participants had content gaps, alternative conceptions and confusions on the basics of the topic. The next items (1.6 - 1.15) to be discussed tested electromagnetic induction and focused on the gaps, challenges and alternative conceptions that participants have regarding this concept that is central to electrodynamics.

Item 2.1: *A current carrying conductor placed in an external magnetic field experiences a force.*

Less than half of the participants (41.9%) knew that the direction of the force experienced by the conductor depends on the direction of the current flow relative to the magnetic field B , using the left-hand rule to know the direction. The correct answer was ticked by the majority even though is below the 50% margin.

Item 2.2: *Which of the following devices are based on the principles that a current carrying conductor in a magnetic field experiences a force?*

Only 9.7% ticked the correct answer (?) “DC motor” and the majority 91.3% ticked the incorrect answer (D), “an electromagnet”. It looks like a confusion or misinterpretation of the question. It says current carrying conductor in a magnetic

field; not a magnetic material in a conductor (coil) to make an electromagnet (right hand screw rule). Also, a content gap seems to be prevalence since participants/teachers performed poorly in items 1.1 and 1.5 and the basic knowledge in these items relate to this question.

Item 2.3: *Which of the following will NOT affect the power output available from a particular AC generator?*

The results revealed that 41.9% of the participants correctly answered the question and this is the highest percentage of the options. The question was testing basic knowledge with regard to categories affecting the speed of rotation of a generator (output). The result seems to be an out-shooter that differs from the results of other items. This is probably because it could be easily identified or remembered from grade 12 question papers as it is one of the regular questions; hence it was answered more correctly as compared to other items.

Item 2.4: *The direction in which an induced current flows depends on*

- A. Ohm's law
- B. Kirchhoff's law
- C. Lenz's law
- D. Faraday's law

The direction in which an induced current flow depends on Lenz's law and not Faraday's as the majority of the participants indicated. Only 3.2% answered correctly with the majority (64.5%) indicating the answer as Faraday's law. The researcher believes that the reason for the seemingly confusion of the two laws is due to guess work and participants went for the more familiar law usually asked in the FET exam papers, namely Faraday's law. Thus, according to Faraday's law, a current is induced in the wire which by Lenz's law is in a direction such as to produce magnetic flux to oppose the change in flux.

Item 2.6: *The magnitude of induced EMF depends on*

- A. Rate of change of magnet flux with respect to time
- B. Rate of change of electric flux with respect to time

C. Rate of change of voltage with respect to time

D. Rate of change of induced current

Only 38.7% correctly answered the question by indicating that “the magnitude of induced EMF depends on” the rate of change of magnet flux with respect to time (option A). For example, the faster you plunge a magnet into or pull it out of a coil, the greater the induced EMF.

Item 2.8: *What happens when you turn off current in an electromagnet?*

The majority (38.7%) of the participants, although below the 50% margin, ticked the correct answer “the magnetic field reduced to zero”. This is an indication of the content gap that a magnetic field is created by a current and does not exist around the conductor when no current flows. This is a basic concept and since it is an application of electromagnets done in the Grade 9 syllabus.

Item 2.10: *Consider the situation below and choose the relevant statement.*

A picture shows that the North Pole of a magnet is pushed into a coil and the question tested Lenz’s law. Only 35.5% ticked the correct answer which is option C. This question was extracted from the 2014 grade 11 final exam question paper that was written by their learners but could not be answered by the majority of the participants. The results also correspond to that of Item 2.4, which was not well-responded to as well. Furthermore, the confusion of ‘being in opposite direction’ with ‘opposes the changes was detected, as it was in accordance to the findings of Mauka and Hingley (2005: 1165).

The participants’ conceptions revealed in the items as discussed above were further analysed and discussed with the aid of statistics. These items of Parts 1 and 2 of the questionnaire were grouped and categorised based on the conceptions tested for a deeper understanding of participants’ conceptions. The next section analysed these categories of concepts.

6.3.2 Category analysis of groups of items

This statistical analysis aimed at organising and making sense of participants' broad understanding of concepts related to the topics. Category validity is the extent to which a test measures a theoretical concept or trait, such as intelligence. In this study, the trait measured and tested in category of knowledge of concepts as done by Pedhazur and Schmelkin (1991).

The researcher wanted to understand participants' perception and understanding of concepts that were associated. The analyses were to indicate types of collective intellect for questions of description appearing in different situations but falling in the same categories. Progression of knowledge from simple to complex was to be analysed.

Part 1 and 2 items of the questionnaire were analysed by the researcher to establish whether related items form a category and to determine correlations between participants' responses to different items. The items were divided into four categories, namely: Sources of magnetic fields; Interaction of magnetic fields, Lenz's law and electromagnetic induction.

Table 6.3 to 6.7 below present results per knowledge area (category) and the overall percentages of all participants were used to establish consistency of performance in answering the category of knowledge. Comparisons of responses to items within and between the categories were analysed to establish consistency in responses and to discuss reasons for such responses that were not consistently responded to. Consistency in a category would refer to the essence of reliability in answering items within a specific category, that is; if one item is correctly responded to, then the other within the same category should also be correctly responded to with a high probability. The following discussion present the theoretical categories of items and the results obtained before the intervention. The 50% margin and 30% margin are still applied in the discussion.

- **Category 1: Sources of magnetic fields**

Table 6.3 below presents the response of teachers/participants to items related to pre-knowledge on sources of magnetic fields.

Table 6.3: Participants' responses on sources of magnetic fields

Questions	Control (15)		Experimental (16)		All participants (31)	
	total	%	Total	%	Total	%
1.2A	8	57.1	11	68.8	19	61.3
1.2B	9	64.3	5	31.3	14	45.2
1.2C	1	7.1	1	6.3	2	6.5
1.2D	2	14.3	7	43.8	9	29.0
1.4	4	30.8	5	38.5	9	29.03
2.7	11	84.6	7	50.0	18	58.1
2.8	7	53.9	5	33.3	12	38.7
Average		44.6		38.8		38.2

All items grouped as category 1, participants' response was below the 50% margin to all the items except Item 2.7 to which the response was 58.1%, and item 1.2 A to which 61.3 % responded correctly. Participants' response to four out of seven items in this category is below 30% and was regarded as content gaps, confusion, alternative conceptions or a challenge. The average response of 38.25% indicated overall performance in this category and was below the agreed margin and that implied content gap on sources of magnetic field.

In this category, electrical and magnetic fields are confused by the participants, since the same source, the electric charge, can produce both fields. The participants attributed both fields to electric charge, without mentioning whether it is in movement or at rest. The results revealed problems concerning sources of the magnetic field, which was also indicated by Guisasola *et al.* (2003:444-464).

- **Category 2: Interactions in magnetic fields**

Table 6.4 summarises the response of the combined group participants in the second category questions that investigated participants' perceptions of interactions in magnetic fields. This category is aimed at detecting participants' explanations of basic magnetic phenomena.

Table 6.4: Participants' response on interactions in magnetic fields

Questions	Control (15)		Experimental (16)		All participants (31)	
	Total	%	Total	%	Total	%
1.1	0	0	5	33.3	5	16.1
1.5	2	13.3	0	0.0	2	6.5
2.1	5	33.3	8	53.3	13	41.9
2.2	1	6.7	2	14.3	3	9.7
Average				25.2		18.5

The items in this category present situations in which the participants must keep in mind that only moving charges produce magnetic fields and not stationary charges. Although the concept of charge is fundamental in both electricity and magnetism only an electric field (E) is associated with any charge, whether stationary or moving. Interactions of a bar magnet's magnetic field on a moving charge is explained by the interaction between the two magnetic fields, one produced by the magnet and the other by the moving charge.

The results in Table 6.4 show that the participants do not possess this fundamental knowledge regarding electric and magnetic fields. Participants' response to all items was below 30% except item 2.1, to which participants' response yielded percentages below 30% with an overall average response of 18.6% in this category. The performance automatically qualifies the category as one in which most participants harbour alternative conception/confusion/content gap in this study. Concepts should constructively progress from simple to complex relations and category two builds on category one. Participants, who do not know when magnetic fields are formed, cannot be expected to know when magnetic fields interact. Existence of more than one magnetic fields in the same environment account for magnetic interaction. Poor performance became worse because the basics were still missing (category one), which indicates the effect of a content gap.

Another striking result in this category was the ineffectiveness of the idea of field lines in participants' reasoning. The visualisation of field with the aid of field lines is used to explain magnetic interactions between two opposite charges or two opposite poles of a bar magnet. Learners may confuse electric and magnetic fields because

the field lines due to these interactions look similar as indicated in Figure 3.3 of Chapter 3.

This confusion due to visual similarities implies that analogical reasoning can pose learning difficulties. The weak performance and challenges indicated in this category would then mean that networks of concepts should be built by focussing attention to concepts from different topics and relating them while pointing out both similarities and differences. Concepts should not be learned in isolations but be connected.

- **Category 3: Induction**

Table 6.5 below presents the response of participants to items related to pre-knowledge and general understanding of induction.

Table 6.5: Participants' responses on induction

Questions	Control (15)		Experimental (16)		All participants (31)	
	Total	%	Total	%	Total	%
2.3	4	28.6	9	60.0	13	41.9
2.5	1	7.7	3	18.8	4	12.9
2.6	3	23.1	9	60.0	12	38.7
2.9	1	7.1	10	71.4	11	35.5
Average		16.6		52.5		32.3

All items in the category on induction (Table 6.5) were performed below the 50% margin and only Item 2.5 below 30%. The average of 32.26% indicated the overall performance of that category and the responses were better (above 30% margin) as compared to the other two categories already discussed. The expectation would have been the opposite because the two content knowledge categories above are basic knowledge that underlies the concept of induction. Category three builds on categories one and two and in the latter underperformance was expected to affect induction. The response in this category seemed to be the cause of rote learning, since there were content gaps of the basic knowledge. This response can bear testimony to traditional teaching and rote learning. Better response in this category did not guarantee meaningful learning and understanding and conclusions about the issue are further discussed in the next Chapter.

- **Category 4: Lenz's law**

Table 6.6 below presents the response of participants' to items related to pre-conceptions and understanding of Lenz's law before the intervention.

Table 6.6: Participants' response on Lenz's law

Category 4: Lenz's law						
Questions	Control (15)		Experimental (16)		All participants (31)	
	Total	%	Total	%	Total	%
2.4	0	0.0	1	6.3	1	3.2
2.1	5	35.7	6	40.0	11	35.5
Average		17.9		23.1		19.4

Only two items (item 2.1 and 2.4) were grouped in the category of Lenz's law, thereby making comparison very difficult. Both items performed below the 50% margin with Item 2.4 below 30%. The average of 18.55% indicates that there are serious challenges prohibiting the understanding of concepts within that category.

The indication of the discussion of Item 2.10 in 6.3.1.1 was that the question was extracted from the 2014 grade 11 final question paper that was written by the learners taught by the same participants, so the participants might have identified it, hence the better performance in that category. The expectation was that the two items (2.1 and 2.4) tested Lenz's law and consistency in answering was expected. Item 2.4 performed at 3.2% and support the discussion of the category 3 results on induction. Lenz's law is part of the induction theory.

- **Summary of results**

Table 6.7 consolidates and gives a summary of the average response to items of the different categories in percentages and also presented graphically in Figure 6.1.

Table 6.7: Consolidation of average response to items of categories

Category (# = number of items)	Item number	Control	Experimental	All participants
		%	%	%
Source of magnetic field (# = 7)	1.2, 1.4, 2.7, 2.8	44.6	38.8	38.2
Magnetic fields (B) interaction (# = 4)	1.1, 1.5, 2.1, 2.2	15.7	25.2	18.5
Induction (# = 4)	2.3, 2.5, 2.6, 2.9	16.6	52.6	32.3
Lenz law (# = 2)	2.4, 2.10	17.9	23.1	19.4

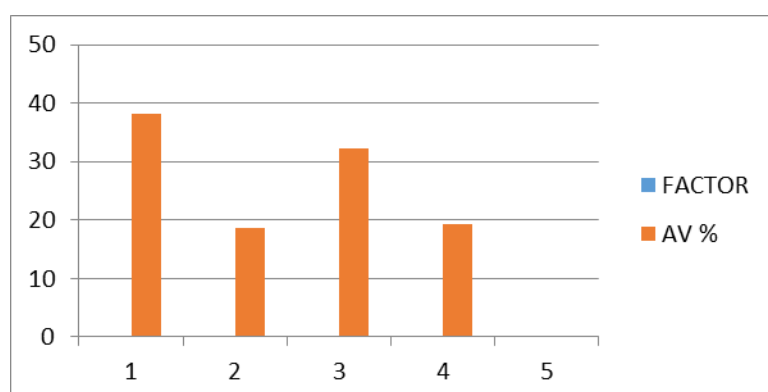


Figure 6.1: Graphical representation of average response to category

The responses of Table 6.7 and the bar graph above (Figure 6.1) indicate that in all the categories the average performance was below 40%. Response to sources of magnetic field (category one) was the better performance at 38.2%. Then the worst response was category two items related to magnetic field interaction at 18.5% and response to category four (Lenz law) was also poor as in category two at 19.4% Watts (1994:52) indicated the constructivist approach as the formation of concepts arising through the interaction between previously accumulated knowledge and current data. Generally, there was no consistency in responding to items related to previously learned knowledge (basic concepts) and existing knowledge of

electrodynamics. There were gaps between basic concepts and knowledge of electrodynamics. It would then imply that most participants do not have an adequate knowledge of the concepts of electrodynamics, since all response to all the items were way below the 50% margin.

Mäntylä (2011:1) indicated two central goals in physics teacher education: firstly, to learn the structures of physics knowledge and secondly the processes of its construction. To know the structure is to know the framework of concepts and laws on that topic, from basic to abstract and from known to unknown. Then to know the process is to know where the knowledge comes from, how the framework is constructed and how it can be justified. The constructivist way of learning could bring the solution to this problem.

6.4 QUANTITATIVE ANALYSIS AFTER INTERVENTION AND LEARNING GAINS

Creswell (2009:11) indicated that studies have shown that a pre and post-test method provides a valid measurement of the impact of an intervention. The average normalised learning gains (Hake, 2002:3) were calculated from the results of the pre- and post-tests to evaluate the effectiveness of the interventions with the experimental and control groups.

The next table (Table 6.8) summarises the analysed the results obtained from the same questionnaire that was used as pre-test before and as post-test after the intervention. The average normalised gain was calculated from the means for each question. This was aimed to determine the impact of simulations and practical work on participants' knowledge gain and understanding of the core knowledge (induction) of electrodynamics. Table 6.8 excluded the first five items as they served the purpose of identifying the knowledge gaps from the basic concepts of the core knowledge in the pre-test.

6.4.1 Analysis of average normalised gain of items

The last column of Table 6.8 shows the difference between post and pre-test percentages for the control and experimental groups and the improvement in terms

of the average normalised learning gain (symbol <g>). An example of the calculation of the <g> value of Item 2.1(refer to Table 6.8 below) of the control group follows below:

Actual percentage gain = Post test score - pre-test score

$$= 73.3 - 33.3$$

$$= 40$$

Maximum possible gain = Total possible gain - Actual gain

$$= 100 - 33.3$$

$$= 67.3$$

Average Normalised gain = $\frac{\text{Actual percentage gain}}{\text{Maximum possible gain}}$

$$= \frac{40}{67.3}$$

$$= 0.6$$

Table 6.8: Comparison of the normalised learning gains per item for the control and experimental groups.

Q #	CONTROL GROUP			EXPERIMENT GROUP		
	Pre-test %	Post-test %	gain <g>	Pre-test %	Post-test %	gain <g>
2.1	33.3	73.3	0.6	50.0	87.5	0.8
2.2	6.7	20.0	0.1	12.5	37.5	0.3
2.3	26.7	80.0	0.7	56.3	68.8	0.3
2.4	0	20	0.20	6.25	62.5	0.60
2.5	6.7	40.0	0.4	18.8	56.3	0.5
2.6	20.0	60.0	0.5	56.3	68.8	0.3
2.7	73.3	46.7	-1.0	0.0	62.5	0.6
2.8	46.7	33.3	-0.3	31.3	37.5	0.1
2.9	6.7	40.0	0.4	62.5	56.3	-0.2
2.10	33.3	60.0	0.4	37.5	56.3	0.3

Discussions

From the average normalised learning gains (Table 6.8) it can be deduced that the experimental group showed a larger conceptual improvement in almost all aspects of the questionnaire except for Item 2.3 and 2.9 where the control group performed

better than the experimental group. The results further show that, out of ten (10) items in the questionnaire, only one item (item 2.9), has a negative $\langle g \rangle$ -value for the experimental group. This item was testing the knowledge of participants on the importance of the change of flux to cause the flow of charges and was supported by the video recording discussion in 6.5.1.2 under aspect of induction (refer to Appendix J). Simulations were used to clarify the theory, but still the performance dropped. Jensen (2008:173) indicated that during the learning process and concepts elaborations, alternative conceptions can form and learners may reject the correct scientific information. Alternative conceptions contain strong knowledge structures that are inconsistent and difficult to cure. Conceptual development can be difficult to accomplish in a short while since it is not simple to change existing mental schemas. This could mean that the intervention may not have adequately addressed the problem in the available time (Meyer, 2014:8).

Another possible reason for the negative $\langle g \rangle$ -value (performance drop) could have been caused by the way the question was phrased as opposed to the experiment that was executed to clarify the concept. The question emphasised the generation of electricity from rotating magnets. The experiment that was demonstrated showed generation of electricity as a wheel connected to the generator. Since the components of the generator were not visible, the participants' attention was probably drawn to the wheel rotation that they observed, rather than rotation within the generator that were not visible. The way the question was asked, might have mislead the participants. Instead, the question should have referred to the change in magnetic flux caused by the movement of a conductor or magnet to be more in line with the experiment.

Except for a few items (item 2.7 and 2.9), the results indicated that the combination of experiments and simulations aided in clarification of the concepts in electrodynamics and that the results showed better conceptual understanding in the experimental group than in the control group. The best learning gains for the experimental groups were obtained in items 2.1, 2.4 and 2.7. The good performance was credited to the impact of simulations and experiments that related to the three aspects that were tested. The relevance of the experiments and simulations can be referred to Appendix H and I. Item 2.1 was covered by experiment 3 and simulations

5 and 6; Item 2.4 covered by simulation 7; and Item 2.7 covered by experiment 2 and simulation 4. These results are further elaborated and outlined in the next three paragraphs.

Item 2.1 tested the pre-conceived knowledge on a current carrying conductor placed in an external magnetic field thereby experiencing a force and was underperformed in the pre-test (refer to Table 6.2 above). Experiment 3 then verified that the current carrying conductor placed in a magnetic field experience a force (refer to Appendix H) and simulation 5 and 6 (the motor effect) further emphasised this.

Item 2.4 tested the direction in which an induced current flows if a magnet is pushed in and out of the solenoid (concept of induction). Simulation 7 was presented to show the direction of induced voltage when pushing the North or the South Pole in or out of a solenoid. After the intervention, there was a practical significant knowledge gain of 0,6 with the experimental group as compared to a small gain of 0,2 with the control group (refer to Table 6.8)

Item 2.7 tested the participants' pre-conceived knowledge on the process of making an electromagnet and the performance was very poor for both groups in the pre-test. During the experimental intervention, experiment 2 investigated the relationship between electricity and magnetism and simulation 4 (on electromagnets) further emphasised the relationship. Consequently the experimental group obtained a practical significant learning gain of 0,6, while the percentage of the control group dropped in the post-test, yielding a significant negative learning gain of -1,0 (Table 6.8).

The graphs below (Figures 6.2 and 6.3) were used to indicate the difference in performance of the participants from pre-test to the post test. Item numbers given on the x-axis, is covering only part two of the questionnaire.

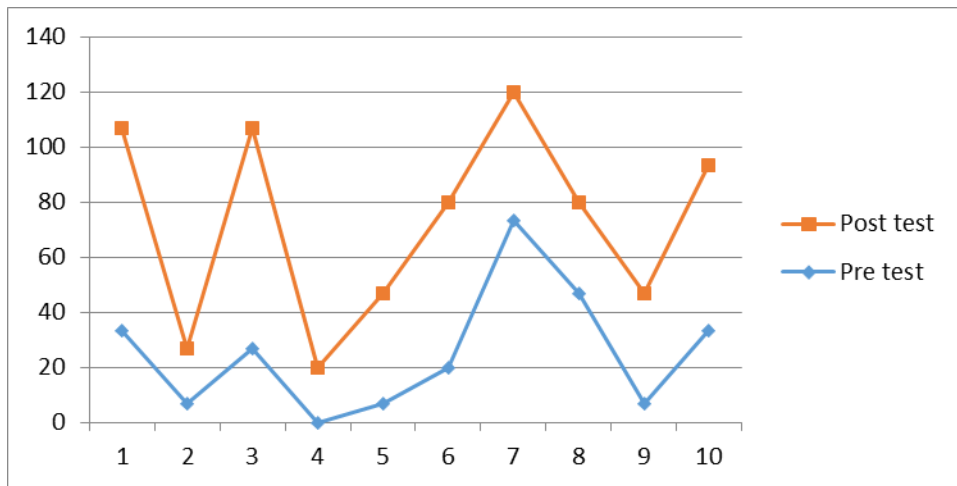


Figure 6.2: Graphical representation of pre-test and post-test of the control group

Summary of conceptual development model

From the graph, it is evident that in average the participants improved their marks after the topic electromagnetism was taught to them. But when we compare Figure 6.2 to Figure 6.3 below, it further confirms that the teachers in the experimental group have better knowledge gain than the teachers in the control group who had marginal knowledge gain after the intervention.

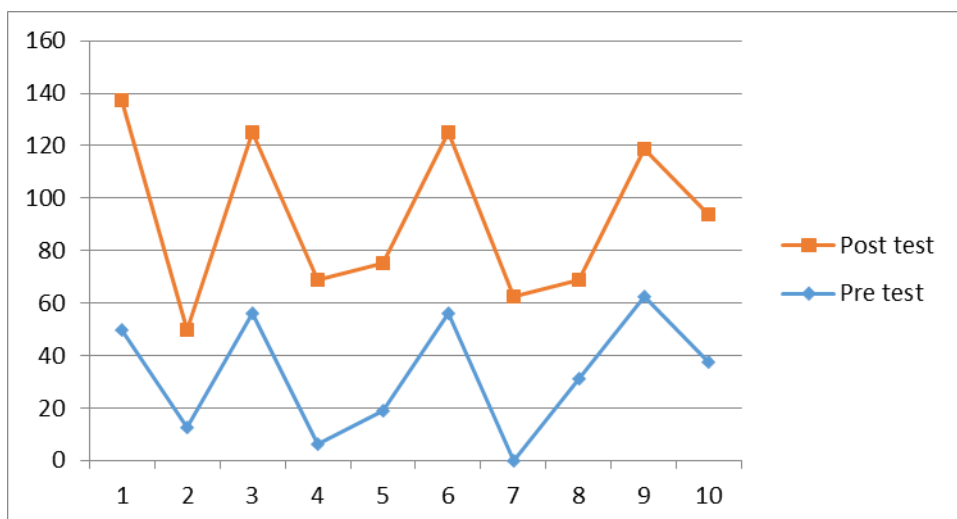


Figure 6.3: Graphical representation of pre-test and post-test of the experimental group

The aim of this study was to investigate the impact of a teaching sequence (conceptual development approach with the use of experiments and computer simulations). Computer simulations and experiments had its own impact, but clarity and explanation and teaching of concepts was done in a constructive way (conceptual development approach) for the participants to understand. Conceptual development approach also impacted positively for knowledge improvement of both groups. Progression of theoretical concepts was explained in detail and drawings were used to emphasise content as well (refer to video). The learning gains of 0.8 in 2.1 (refer to table 6.8) was the outcome of conceptual development teaching. Explanation in terms of vector properties, indicating the vector sum as the two fields (B) interact (i.e. the fields of the bar magnet and electric current) was done theoretically. Thorough and detailed explanations with the use of drawings impacted positively (refer to video or appendix J section 2). When the two magnetic fields interact in such a way that they are in the same direction, they combine to increase the vector sum or magnitude. Where the two fields are directed oppositely, they cancel out such that the vector sum decreases (magnitude decrease). The side with the bigger magnitude due to the vector sum, will push the conductor (moving charges), to the side with a smaller magnitude. The conductor moves (when the charges experience a force) towards the side with a smaller magnitude of the force.

6.4.2 Average normalised gain of the category analysis

The analysis in tables 6.9 were done to determine the conceptual improvement of the concepts (items) under the same category and the average normalised gain per category after intervention. The overall percentages of different categories before and after intervention are presented in Table 6.9 below. The analyses were done to determine the conceptual gain in the category of concepts taught under electromagnetism in this study.

Table 6.9: Categorised items results

Pre-test % and post-test %				
Moving charge producing magnetic field				
#	CONTROL		EXPERIMENT	
1.2A	57.1	73.3	68.8	56.3
1.2C	7.1	13.3	6.3	12.5
1.2D	14.3	20.0	43.8	31.3
1.2E	0.0	6.7	12.5	12.5
1.4	30.8	45.5	38.5	66.7
Average	21.9	31.8	33.9	35.8
Magnetic fields (B) interaction				
	CONTROL		EXPERIMENT	
1.1	46.2	45.5	33.3	30.8
1.5A	30.8	64.3	16.7	56.3
2.1	33.3	73.3	50.0	87.5
2.2	6.7	20.0	12.5	37.5
Average	29.2	50.8	28.1	53.0
Induction				
	CONTROL		EXPERIMENT	
2.3	26.7	80.0	56.3	68.8
2.5	6.7	40.0	18.8	56.3
2.6	20.0	60.0	56.3	68.8
2.9	6.7	40.0	62.5	56.3
Average	15.0	55.0	48.4	62.5
Lenz law				
	CONTROL		EXPERIMENT	
2.4	0.0	20.0	6.3	62.5

The learning gains of the items in each of the categories were also presented graphically in Figure 6.4 to show the learning gains in each category.

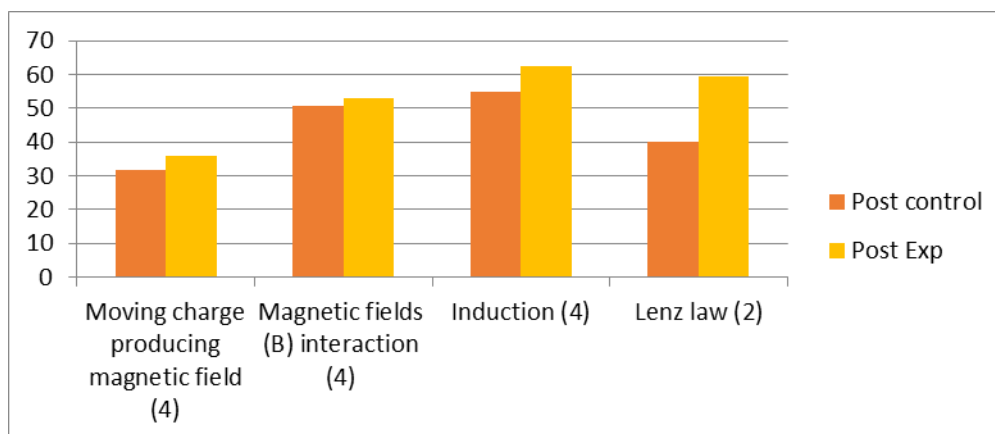


Figure 6.4: Post test results of the two groups

Figure 6.4 and the tables 6.9 confirm that the participants in the experimental group have generally performed better than the participants in the control group after the intervention. The results further proved that the teaching sequence that incorporated experiments and simulations in conceptual development impact positively for knowledge gain. In Figure 6.4 the control group showed minimal and limited gains in almost all the aspects of the test as compared to the experimental group. Comparing the average percentage per category in Figure 6.9 indicates that the impact of the intervention to experimental group is better as compared to the impact of intervention implemented in the control group. This can be attributed to the impact of use of the simulations and practical observations (research aim) which helped the participants to understand the concepts and allowed them to construct their own understanding through concept refinement. This is an important component of the constructivist's theories as discussed in the theoretical framework (refer to 1.3.2 of Chapter 1).

6.5 QUALITATIVE DATA ANALYSIS

Open ended questions, part 3 of section B of the questionnaire (refer to Appendix E) and video recordings were qualitatively analysed and were supported and supplemented quantitative data analysed above.

6.5.1 Qualitative analyses of the video recordings

During the intervention videos were recorded and analysed qualitatively to provide a deeper understanding of the research problem. Recordings of video-taped activities

were viewed repeatedly and coded continually and the following research questions (refer to 1.4.2) were prioritised to be answered by the analysis of the video recordings.

- What challenges do physical sciences teachers experience in their teaching of electrodynamics?
- What conceptual difficulties (knowledge gaps and alternative conceptions) do these teachers have regarding electrodynamics and underlying concepts?
- How does conceptual refinement address the teachers' conceptual difficulties and accomplish knowledge improvement regarding electrodynamics and underlying concepts?

6.5.1.1 *Video recordings before the intervention: participants' reflections*

Before the intervention, participants were asked to reflect, discuss and write concepts in electromagnetism / electrodynamics that they think were difficult for the learners to understand and / or were difficult for them to explain to learners. Each participant was then asked to read out what they have written and the researcher (facilitator for the workshop) was summarising the points on the board, at the same time identifying points that were repeated as they were reading. A discussion of the points then followed and participants were asked to give reasons why they think the concepts were difficult.

The bolded points outlined below were given / written by the participants in the template (refer to Table 5.1 of Chapter 5) that was provided by the researcher / facilitator at the beginning of workshop. According to the participants these concepts are difficult for their learners to understand and for participants to explain. All these points are part of the physical sciences syllabus. In the discussion, the researcher was emphasising that participants should explain why it is difficult to teach the concepts or why they think the concepts are difficult for the learners to understand. The researcher categorised the points to form categories and these points are given in bold below and discussed.

Faraday's law and Lenz's law: These two laws were difficult for participants to explain to learners because the concepts were also a challenge to them.

Interpretation of a negative sign in the equation $E = - \frac{\Delta \Phi}{\Delta t}$: The negative sign represents the fact that any current generated by a changing magnetic field in a coil produces a magnetic field that opposes the change in the magnetic field that induced it. This phenomenon is known as Lenz's law. The direction in which an induced current flows depends on Lenz's law. Thus, according to Faraday's law a current is induced in the wire, which by Lenz's law; is in a direction such as to produce magnetic flux to resist the change in flux.

Calculation of magnetic flux and calculation of EMF versus the angle: $E = - \frac{\Delta \Phi}{\Delta t} = \frac{BA}{\Delta t} \cos \theta$ ($\Phi = BA \cos \theta$): A changing magnetic field, such as a magnet moving through a conducting coil, generates an electric field (and therefore tends to drive a current in such a coil). This is known as Faraday's law mathematical representation: E is the electromotive force or EMF (the voltage generated around a closed loop) and Φ is the magnetic flux that is the product of the area times the magnetic field normal to that area. This definition of magnetic flux is why B is often referred to as magnetic flux density. While most participants were able to state the formula for magnetic flux, many were unable to define it, or to apply the formula to simple problems.

Difference between a motor and a generator: The participants indicated the difference between a motor and a generator as a challenge for the learners. A changing magnetic field, such as a magnet moving through a conducting coil, generates an electric field (and therefore tends to drive a current in such a coil). This is an application of Faraday's law and is foundational to the understanding of generators and motors.

Transformers: Transformers specified in the participant reflections as difficult, but it is only intended to in a very small section under the topic of induction in grade 11. The participants mentioned that their learners perform calculations by substitution of concept values to the equations. Transformers are treated in isolation when teaching and not related to Faraday's law.

Another aspect that was stated in the participant reflections was that the topic in general was a challenge for both learners and participants. They were not more specific in identifying the participants' problems.

6.5.1.2 *Video recording during intervention*

During the intervention of the experiment group, the whole process was video recorded to allow the researcher to repeat, review and interpret the data for analysis. The intention of the review of the video was to understand the participants' challenges. The points outlined below are the content knowledge gaps, alternative conceptions, and other challenges that were displayed by the participants during intervention.

Interaction of magnetic fields: The participant incorrectly argued that if there was a stationary charge in between different poles of two magnets, the charge will move. Though the participant did not mention to which direction the charge will move, the emphasis was that it will move, refer to video transcripts in Appendix J. During the intervention, the participants confused stationary charge with stationary conductor. A stationary conductor with charges moving is referred to as a current carrying conductor in the FET syllabus. Participants could not think of or imagine a single isolated charge moving, it has always been charges moving in a conductor. This explains the poor performance to Item 1.6 of the questionnaire.

The earth's magnetic field: Among the long discussions on the 'interaction of magnetic fields' came out the topic on the earth's magnetic field. The indication of the earth's magnetic field being strong at the poles and explains the 'auroras lights' was questioned by the participants. The discussion was further that during the interaction of the magnetic fields of a current and of a bar magnet, a third magnetic field, namely that of the earth, should also interact and the results should be due to the combined effect of the three magnetic fields. The question was how and when does the magnetic field of the earth feature. The underlying alternative conceptions seem to be that the earth's magnetic field should be large because the earth is large. They do not realise that the magnetic field of a bar magnet or a current-carrying conductor can be larger than the earth's magnetic field at a specific position on the earth.

A charge moving parallel to the magnetic field will not experience a force: A stationary charge (discussed above) and a charge moving parallel to the magnetic field will not experience a force. Charged particle(s) that is moving in a magnetic field experience a deflecting force greatest when moving at right angles to magnetic field lines and zero when moving parallel to the magnetic fields: “How do we explain to the learners why a charge moving parallel to the field (B) will not experience a force, from the equation $F=qVB$, because that charge is moving with the velocity V between the bar magnets?” What brought the confusion was that the explanation says, if the charge is moving, it creates a magnetic field that will interact with the one of a magnet. The missing link was that during the interaction the two fields may combine or cancel such that no force will be experienced by the charge. Furthermore, when moving parallel to an external field, the magnetic field of a charge is directed perpendicular to this field and does not have a component along the field that can interact.

Position of the coil and the flux value: One of the longest arguments that came out during the intervention or content workshop refer to the relative position of the coil to the magnetic field and the flux value, as illustrated in Figure 6.6. The angle θ between the coil and the magnetic field ranging from 0° to 90° caused immense confusion. They did not understand when is the value of flux (Φ) equal to zero and when is it maximum and what happens to the value of the EMF between these two values (from 0 to 90%). Participants incorrectly argued that when the coil is perpendicular to the magnetic field (as in Figure 6.6 (a)), the EMF is zero and when it is parallel (b), it will be a maximum. An example of this line of reasoning is given in the passage of video transcript attached as Appendix J. These arguments of the participants would have been true if they used the term FLUX (Φ) instead of EMF.

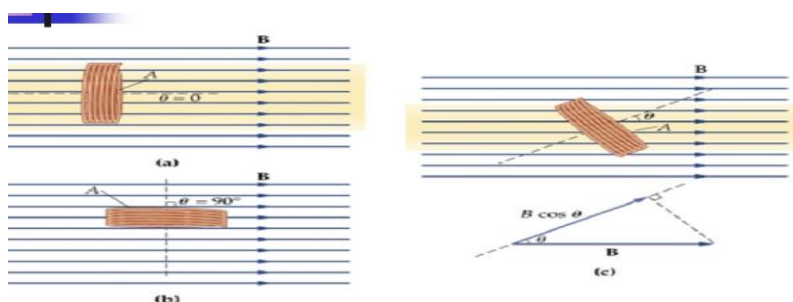


Figure 6.5: Different positions of the coil in a magnetic field

It is clear from their reasoning that the participants confused the minimum and maximum values of the EMF with that of the flux. They consequently did not realise that an EMF is only induced when the flux through the coil **changes** and consequently differs from that of the flux. For example, when the coil is held perpendicular to the external magnetic field, the flux has a maximum value, but the EMF is zero because no change in flux occurs.

Mathematically, the magnetic flux through a loop of area A is $\Phi = B A \cos \alpha$ where α is the angle between the normal to the loop (or coil) and the magnetic field. The EMF is negative to the rate of change of the flux (if the loop is perpendicular to the field, $\alpha = 0$ and hence $\Phi = BA$ (maximum). For a loop parallel to the field, $\alpha = 90^\circ$ and $\Phi = 0$ when the loop rotates from perpendicular (maximum flux) to parallel to the field (zero flux), the change in flux is

$$\Delta\Phi = 0 - \max = -\max$$

$$\text{And the EMF} = -\frac{\Delta\Phi}{\Delta t} = +\frac{\Phi_{\max}}{\Delta t}$$

Induction: if a wire is moved through a magnetic field so that the magnetic flux changes, the charges in the conductor will be acted upon by the magnetic force. This force will move the charges in the wire. Because of this, a potential difference between the ends of the conductor will be induced. This statement was one of the aspects that prompted arguments and questions during the intervention or workshop, refer to the transcript of the video, (Appendix J). The following examples bear reference: A participant who is seeking clarity asked what causes the flow of charges in the conductor. Others further asked clarity as to what happens to the magnetic fields created by the moving charge.

6.5.2 Qualitative analysis of the questionnaire

6.5.2.1 Analysis before intervention: Part 3 of the questionnaire

Part 3 of section B of the questionnaire contained open ended questions and assessed electrodynamics applications. Table 6.10 below gives the results of part 3 of the questionnaire (refer to Appendix E) before the intervention for the combined group. Since the answers of the questions entailed writing and reasoning, they were

considered as yielding qualitative data. The results are given for both individual groups and for the combined group. The results indicated the participants' answers (correct, partially correct and incorrect answers) and the last column show questions not attempted (refer to 6.10). Both groups of participants were taken as one population to analyse part 3, for the same reasons stated in paragraph one of 6.3 above. Number of participating teachers (#) and average (%) are tabled.

Table 6.10: Response for applications of electrodynamics (Part 3 of the pre-test results)

QUESTION	CORRECT		PARTIALLY CORRECT		INCORRECT		NO ATTEMPT	
	#	%	#	%	#	%	#	%
3.1	0	0.0	9	29.0	6	19.4	16	51.6
3.2	5	16.1	7	22.6	1	3.2	18	58.1
3.3	0	0.0	11	35.5	4	12.9	16	51.6
3.4	3	9.7	6	19.4	2	6.5	20	64.5

Question 3.1: *Give two differences between the operation of a motor and a generator*

None of the participants provided a completely correct answer as it was required by question 3.1. Only 29% of the participating teachers were partially correct, meaning they were able to provide one difference instead of two. The one difference, namely the energy conversions that occur, was stated as was expected in grade 12 exam type questions. Not a single participant stated another difference. A possible reason for knowing the answer is recognition of the question from the grade 12 syllabi which supports the findings of categories three and four in section 6.3.2 above.

Concept confusion of what energy conversion is applicable to motors and generators occurred amongst the majority of the participants. *(The correct answer is; Electrical to mechanical energy for motors and vice versa for generators).*

The results indicated that 19.4% of the participating teachers answered incorrectly while 51.6% did not attempt to answer the question, totalling participants who did not know the correct answer to 71%. The higher percentage confirms that most participants lack content knowledge of electrodynamics. Three more common

incorrect answers extracted from participants' answers are quoted in italics and analysed below:

- *“Change in flux produce rotation”*: Confusion of the two power machines is identified in this case: change in flux produce or induce current in a conductor for a generator and current produces motion (rotation) because of the interaction of two magnetic fields.
- *“Motor is application of Lenz law”*: The reason for this idea could be emanating from the direction of rotation emphasised in the grade 12 topic on motors and that Lenz's law also indicates direction. However, Lenz law is not applicable here as it gives the direction of B produced by an induced voltage. The participants thus seem to make connections between the two different situations (electric motor and Lenz's law) because of the emphasis on direction in both.
- *“Motor uses engine to operate and generator uses a fuel”*: The first part could be referring to a motor car having an engine and the second part may refer to the generators at home using petrol (fuel) to operate. It thus seems as if this 'naïve idea' resulted from everyday life experiences or observations.
- *“A generator generates electric current and a motor uses magnets to produce an electric field”*: The second part does not make sense but the part of the statement saying, “Magnets to produce electric field” also hazards a serious alternative conception.
- *“The motor operates through the assistance of an electromagnet while the generator operates through the assistance of current electricity”*: This may follow from incorrect learning prior to electrodynamics applications.

Question 3.2: *Why is an AC generator used at power stations and not a DC generator?*

The results revealed that only 16.1% of the participating teachers gave the correct answer and 22.6% partially correct. Both percentages show poor performance and is confirmed by the large percentage (58.1 %) who did not even attempt to answer the question. Only one participant (3.23%) provided an incorrect answer and the partially correct responses indicate incomplete answers. Examples of participants' incorrect ideas are quoted and discussed below

- *“AC can be transformed and DC cannot”*: Language could be the issue in this case; the participant is trying to say stepped up/down instead of transformed. The noun transformer was incorrectly associated with the verb transform.
- *“AC generator has got an accelerated current that is distributed to the other parts of the national grid, e.g., factories, houses etc.”* This reasoning seems to imply rote learning about the national grid. It is interesting to note that the participant could possibly have thought that AC is the acronym for “accelerated current” (instead of alternating current).
- *“Because of constant current and voltage”*. This incomplete answer also indicates a lack of knowledge.
- The percentage for ‘no attempt’ (50.0 %) to this question clearly indicates that participants lack knowledge of applications of electrodynamics. It also seems to be difficult for them to apply theory in practice.

Question 3.3: *Is the current at our home dwelling AC or DC? Motivate your answer by giving examples at home.*

None of the participants provided the correct answer and the 35% for the partially correct was because of the way the question was structured, that is either choosing AC or DC as an answer, thereby qualifying one to be partly correct for having chosen AC. However, those who chose the correct answer (AC) could not provide the reason for that, implying that they guessed the answer or remembered it (rote learning).

Similar to Item 3.2 above; 51.6% did not attempt to answer the question. The percentage for ‘no attempt’ further confirms that participants lack knowledge of applications and cannot apply theoretical knowledge in practice. Only 12.9% provided incorrect answers as revealed in the following quotations and analysis:

- *“AC because the connection is parallel if you switch one bulb off, the other remains on”*: The reason given here indicates parallel connection of resistors which is not relevant to the question about the use of AC at home. Guess work and confusion of AC and DC are indicated.
- *“DC because from the main switch it is distributed direct to the house appliances like micro waves, stove and fridge. It is flowing in the conductor from the source*

to the appliance”: Alternative conceptions were identified that appliances use DC and current is “flowing” only in one direction, from the source to the appliance. A complete circuit seems not to be necessary.

- “AC because it is transformed”: Wrong terminology is used. Also refer to bullet one in 3.2 above.

Question 3.4: *One of the applications of a generator is found in power stations. Briefly describe or explain the operation of the generator at a coal fired power station. Also include at least one function of the important parts (Coal, water, turbines) of a coal fired power station in your explanation*

The results revealed that only 9.7% answered correctly and 19.4% partially correct. Both percentages show poor performance and is confirmed by the percentage of 64.5 % who did not attempt to answer the question. This result gives more reason to believe that electrodynamics applications are a problem. Content gaps are revealed in the applications of induction and their inability to apply knowledge to real life examples. This is evident from the following quotations in their responses to question 3.4:

- “Turbines moves the generator (mechanical energy) and produce electrical energy”
- “Water is used to turn the turbines and coal burned is actual current generated”
- “Don’t know the answer”
- “Coal burns and transported through turbines to generate electricity”
- “Generator generates electricity from heat produced by burning coal”
- “As the turbines turns it moves the generator to generate electricity to the national grid the distributed to the house”.

The following paragraphs discuss the analysis of the qualitative data collected after the intervention, namely the data from part 3 of the questionnaire and the participants’ evaluation or feedback. The data provided a broad understanding of the impact of simulations and experiments.

6.5.2.2 *Analysis after intervention: Part 3 of the questionnaire*

The results presented in this section are for both groups after the intervention and pre-test was used for comparison and as a baseline to determine and compare the

improvement of the two groups. The results in Table 6.10 above indicated the participants' answers as correct, partially correct, incorrect answers and the last column indicate questions not attempted. The data of the qualitative part of the pre- and post-test was analysed the same way.

The pre-test as discussed in 6.5.2 above confirmed that participant had content gaps, confusions and alternative conception in the open-ended questions. Some participants even declared by writing in the space provided for answers that they didn't know the answer. Another thing that was identified before the intervention was that reasoning in this part was mostly illogic and naïve and the conclusion was reached that participants do not have an adequate knowledge of electromagnetic induction and applications thereof.

Table 6.11 present a comparison of the percentages of correct answered before and after intervention. It compares the percentage of part 3 of section B of the questionnaire (open ended questions) which assessed applications of electrodynamics applications (refer to Appendix E).

Table 6.11: Comparison of percentages of part 3 of the questionnaire after the intervention for the control and experimental groups

	PRE-TEST	POST TEST	POST TEST
Items number	Combined (%)	Experimental Group (%)	Control Group (%)
3.1	0.0	65.5	26.7
3.2	16.1	50.0	53.3
3.3	0.0	37.5	0.0
3.4	9.7	43.8	13.3

The 'no attempt' option in Table 6.10 of the pre-test results was observed to have the highest percentage than all other option in that table before intervention. The trend observed was that in all items, participants did not bother to give answers and some even indicated that they did not know the answer. Table 6.11 results showed improvement on both groups after intervention, but the experiment group having performed much better than the control group in all the questions except 3.2 where they performed similarly.

Table 6.12 below reveals that, after the intervention for both the control and experimental group, there was an outstanding improvement in answering the questions. Table 6.12 indicates the percentage of participants of the two groups who did not attempt to answer the questions after intervention. One of the findings was that even the control group improved tremendously after their intervention. The researcher believes the reason behind was the effect of the conceptual development model approach which sequenced the concepts in a logic and understandable manner. Probably also is because of the most common and adopted teaching approach generally used as the “survival method” of teaching, where practical work is not made part of lessons at our schools. During the intervention for control group, more time was available to explain all the concepts and to give details than it was with the experimental group who used most of their time in doing practical work and showing simulations

Table 6.12: Comparison of results for no attempt after intervention

	PRE-TEST (%)	POST-TEST (%)	POST-TEST (%)
	Combination	Experimental group	Control group
3.1	51.61	0	0
3.2	58.06	0	0
3.3	51.61	18.77	13.33
3.4	64.52	0	0

6.5.3 Qualitative analysis from the evaluation form: participants’ feedback

The experimental group of participants were requested to complete an evaluation form and give feedback on their learning. The views of participants showed that they accepted the use of computer simulations in teaching even though before the research they were not exposed to it. In the participants’ responses in the evaluation form, supported by the general comments made at the end of the workshop, a general feeling was that the approach was the best. The general comment was that the experiments and computer simulations should be integrated with traditional normal teaching methods. Specific comment on computer simulations were that it makes teaching physics easier and it saves time usually spent in drawing and

labelling diagrams on chalk board and those simulations should be incorporated in the teaching of physics.

The points outlined below provide feedback from the participants on the teaching sequence that was used during the intervention. The template and questions were provided by the researcher, refer to Appendix F and the points were summarised per question from the evaluation form as follows:

- Was the whole workshop well-organised and the facilitator well-prepared?

All the participants (100%) agreed that the workshop was well-organised and that the facilitator was well-prepared.

- Did the workshop meet your expectations?

100% participants indicated that the workshop met their expectation. Some of the comments on this question were that it addressed their frustrations generally on the topic as a whole. It also addressed problems on concepts they have been struggling with.

- Did the workshop address challenges and alternative conceptions as it was discussed earlier (before the intervention) about electrodynamics?

All the participants (100%) agreed that their challenges were addressed and some were specific about alternative conceptions that were cleared and covered under bullet five and six.

- Do you think the teachers engaged well in the workshop?

All the participants agreed with the statement that there was maximum participation. Participants were eager to learn as they were asking questions and clarity.

- Comment on the impact of experiments and simulations on your understanding of electrodynamics. Be as specific as possible.

Some comments were repeated and the following states those that were written most: *"They made the topic easy to understand and clarified the difficult concepts"*. *"They brought concepts to life"*, made the concepts real, and cleared alternative conceptions.

All the simulations that were presented were indicated by participants to be relevant and clarified concepts for knowledge improvement and understanding. Two experiments were highlighted by the participants to have fascinated them, the

induction experiment using a voltmeter to read the induced voltage; and the generator experiment. Both experiments were application of electromagnetic induction and seem to have impacted positively during conceptual development of the electromagnetic induction.

- What did you enjoy most?

The feedback highlighted the practical work, use of simulations and facilitation. How the facilitator engaged the participants and demonstration of the concepts and phenomenon, presentation well-organised. Discussions of activities also mentioned.

- What do you think the facilitators could have done better?

Could have organised the topic earlier before the topic was taught at school because there is now a need to go and repeat the topic. Time for the workshop to allow more experiments should have been extended to a week instead of three days.

- What would you suggest needs to be improved?

“More time for the experiments”, this statement was referring to the period that was allocated for the workshop (intervention), as it was limited. *“Conduct similar workshops on other challenging topic, specifically paper one topics”*, meaning the teaching sequence impacted positively for their knowledge gain, and wanted more of similar workshops.

From the participant feedback and statements, it is evident that such an exercise led to enhancement of their knowledge. Participants appreciated the impact of experiments and simulations and it is worth noting that transmission way of teaching used by participants is not considered an effective and good approach to learning and teaching

6.6 COMMON ALTERNATIVE CONCEPTIONS IN ELECTRODYNAMICS

In this study, common alternative conceptions were consolidated, by comparing the ones identified in this study and the ones identified from the literature review (Chapter 2 of this study). Analysis was made to synthesise and to comprehensively conclude the persisting common alternative conceptions that were regarded as serious challenges in the learning and teaching of electrodynamics. These alternative conceptions are discussed below.

- **Electric charges have a magnetic field (B) irrespective of whether moving or stationary.**

Participating teachers confused magnetic and electric fields by saying a charge at rest can produce magnetic field and that it can be subjected to an external magnetic field even if it is stationary. An electric charge will not be subjected to the magnetic field if it is stationary or even when moving parallel to the magnetic field of the bar magnet

Correct science theory: Electric charge has a magnetic field only when it is moving. It has both an electric and magnetic field when moving, but has only an electric field when it's stationary.

- **Electric fields and magnetic fields can interact.**

This alternative conception still links to the one in section 1.5. The relationship that exists between electric and magnetic fields is a general problem. There is a general alternative conception that a stationary charge can be subjected to a magnetic field because of there is idea that this magnetic field can interact with the charge's electric field. Alternatively, they think a stationary charge has a magnetic field hence they believe the interaction is possible (Bagno and Eylon, 1997:726-734).

Correct science theory: Electric and magnetic fields do not interact with each other. When magnetic fields of different sources are in the vicinity of each other they interact.

Induced current varies proportionately with current in solenoid.

A common alternative conception is that the magnitude of the induced current in conductor / the solenoid is directly proportional to the magnitude of the steady current that produce the magnetic field that induces the current in that conductor or the solenoid. There is a general believe that the more you increase the current, which will automatically increase the magnetic field produced, then either way the induced EMF will also increase (Gunstone, 2007:42).

Correct science: The magnitude of induced EMF depends on the rate of change of magnet flux with respect to time.

- **Only an electric current or magnetic field is necessary for an induced current, not a changing flux.**

The general trend is that, as long as there is current and magnetic field involved or interacting, then voltage will be induced. This will happen irrespective of whether both two important entities are steady, EMF will be induced. Proportionality is attached to the magnitude of the magnetic flux inducing the voltage and not to the rate of change of flux inducing the voltage.

Correct science: A change in either current or magnetic field causes a change in magnetic flux. The induced current flows only when there is a relative movement between magnetic field and the conductor.

- **There is no clear distinction between Lenz's law and Faradays law and their applications.**

There is common concept confusion between the two laws of induction and confirms that there is a misunderstanding of the two laws and their applications. The trend shows difficulties in understanding the induced emf, how it is produced and the directions of that induced current.

Correct science: The direction in which an induced current flows depends on Lenz's law and not Faradays. Thus, according to Faraday's law a current is induced in the wire, this by Lenz's law is in a direction such as to produce magnetic flux to resist the change in flux.

- **Confusion of 'being in opposite direction' with 'opposes the changes'.**

When determining the direction of the induced EMF, 'oppose the change' is interpreted as being in the 'opposite direction', which relates to alternative conception in 2.10 about Lenz law. The phrase "Oppose the change" is interpreted as meaning being in the opposite direction and this creates difficulty in determining the direction of induced EMF.

Correct science: Thus, according to Faraday's law a current is induced in the wire, this by Lenz's law is in a direction such as to produce magnetic flux to resist the change in flux.

6.7 COMPARISON OF CONCEPTUAL DEVELOPMENTS DISCUSSED IN THIS STUDY

Chapter 2 of this study reviewed key concepts and how they relate and progress to form a unit for conceptual development of Electrodynamics. FET band curriculum for physical sciences (DBE, 2013) and historic development of electromagnetism (referred to as electrodynamics in this study) were reviewed to check how concepts progressed to the development of electrodynamics. The review of conceptual development in electrodynamics (chapter 2) was done to set a foundation and platform for conceptual development approach that was to be used for this study, Chapter 2 was reviewed to get the best picture of sequencing the concepts to ensure progress in a way that will not create gaps or alternative conceptions. The two conceptual development orders discussed in this study and the intervention order were tabulated in 6.13 below, for comparison and analysis

Table 6.13: comparison of conceptual developments

INTERVENTION ORDER	HISTORICAL ORDER	FET CURRICULUM for physical sciences (DBE, 2013) ORDER
1. Magnets and magnetic field 2. The earth magnetic field 3. Charge and magnetic field 4. Electromagnets 5. Force on a current carrying conductor in a magnetic field: interaction of magnetic field 6. Electromagnetic induction Laws of electromagnetic induction: Faraday's and Lenz's law 7. Applications in electrodynamics 8. Motors 9. Generators 10. Mutual induction 11. Conservation of energy	1. Electrical and magnetic forces 2. Magnet and Magnetic bodies, Earth 3. Electricity and magnetism 4. Interaction of magnetic fields. 5. Electromagnet 6. Electrodynamics Phenomena 7. Self-induction and mutual induction 8. Law of electromagnetic induction (Faraday and Lenz law) 9. Electro-magnetic field 10. Induction coil.	Grade 10 1. Magnetic and nonmagnetic materials. 2. Magnetic field Grade 11 3. Current carrying wires 4. Right hand rule 5. Application and impact 6. Faraday's law and calculations Grade 12 7. Generators and motors 8. Alternate current (AC) 9. Application

Discussion

Concepts covered in all the conceptual development order

The following concepts were covered in three the compared conceptual development orders (Table 2.4):

- Magnets and magnetic field
- Electricity and magnetism
- Faraday's law applications
- Interaction of magnetic field which is covered by right hand rule in the FET syllabus for physical sciences (DBE, 2011)

Discussion of the missing concepts in any of the conceptual development order

The Earth's magnetic field: It is not part of the syllabus coverage in the FET band (grade 10-12), the historical order only mentioned it without any further discussion, but the intervention order elaborated further on it.

- **Charge and magnetic field:** It was only discussed in the intervention of this study, but there was no mention of that in the other two reviewed concepts developments progressions.
- **Electromagnet:** There was no mention of electromagnets in the FET syllabus for physical sciences.
- **Motors and generators:** Motors and generator were only mentioned but not emphasised in the historical development. The intervention and FET syllabus dwelled deeper onto the concepts and the FET syllabus dwell deeper into calculations.
- **Conservation of energy:** It was only covered in this study and not mentioned in the reviews.
- **Mutual induction:** was mentioned in the historical development and the intervention of this study, refer to (Appendix G), There was totally no mention of mutual induction in the FET syllabus for physical sciences (DBE, 2011).

- **Induction coil** was discussed in the historical development. This was introduced historically by Faraday, but now Faraday's law and its application is included in FET curricula.

The analysis indicated that FET syllabus had many missing concepts that are necessary for the concept development as compared to the other two conceptual development discussed in table 6.13. The evidence supports what the researcher mentioned in 2.5 that the FET syllabus is stagnant and not supporting progression for constructivist learning theory emphasised in the theoretical framework of this study. This can create serious gaps and oppose learner's formation of proper network of concepts in order to understand electrodynamics as a unit and alternative conceptions are more likely to form.

6.8 COMPREHENSIVE DISCUSSION OF ALL RESULTS

In this section a comprehensive, overarching discussion is given, taking all quantitative and qualitative results discussed above into account. The pre-test results are discussed first to show what difficulties and knowledge gaps the participants possessed before the intervention. This is followed by a discussion of the impact of the intervention on these difficulties and knowledge gaps.

Magnetic fields and its interaction: The results of item 1.2d of the questionnaire discussed in 6.3.1.1 above revealed that 6.5% of the participants knew that steady current causes a magnetic field and 93.6% of them did not know. The discussion of Item 1.5 in 6.3.1, the participants mentioned that the stationary charge between the magnets will experience a force. Two correct responses were provided by teachers and both performed at 19.35% and 6.45% respectively for item 1.5 and 6.3.1. The responses were further supported by the video discussed in 6.5.1.2, where participants confused stationary charges with stationary conductors having moving charges. Grade 12 physical sciences syllabus for physical sciences emphasise conductors with charges moving (referred to as current carrying conductor) and therefore the scenario is more familiar to the physical sciences teachers. Participants could not think of or imagine a single isolated charge moving, it has always been charges moving in the conductor in the syllabus. Constructivist way of learning to understand that charges flowing in the conductor in a magnetic field, speaks the

same content with a single charge moving in a magnetic field. Now the missing link creates a gap and confusion. Participants also showed a general lack of understanding the relationship between magnetic field and electric field for stationary charges.

Category 1 of 6.3.2 (Magnetic fields (B) interaction category) above further supports the statement that participants had problems with the concept and could be regarded as a content gap. Participants' responses on all items were below 30% with an overall of 18.55% in that category. The performance automatically qualifies the category to be an alternative conception, confusion, or a content gap. The literature reviews of Chapter 3 also identified the interaction of magnetic fields as an alternative conception. We can indirectly observe electricity through electric appliances on daily basis, but we cannot sense or see magnetic fields, hence the problem. Scientific learning process need to make sense of observations and experiences to build up concepts into a sound and consistent framework of knowledge (Scherr & Redish, 2005:41). Therefore, effective instructional designs such as simulations and or experiments can enable participants and learners to visualise and understand the fundamental ideas such as fields in a better and clearer way (Chen *et al.*, 2012:1) as was confirmed in this study.

A charge moving parallel to the magnetic field will not experience a force and this difficulty was evident in Item 1.5. A stationary charge (discussed above) and a charge moving parallel to the magnetic field will not experience a force, even if it was moving (having its magnetic field). During the interaction, the two fields may combine of cancel out such that no force is experienced by the charge. This further gives the reason why the interaction of magnetic fields was a problem. The concept of the earth's magnetic field was also raised during the intervention; there were confusions and gaps about the concepts among all the participants due to insufficient knowledge and understanding.

Induction: The pre-test results in this study revealed that most participants do not have an adequate knowledge of electromagnetic induction. Participants' alternative conceptions, confusions and conceptual difficulties were exposed by the pre-test results as discussed in 6.3.1 of Chapter 6, with the performance below 50% and even worse below 30%. All knowledge of items performed below 30% were

automatically regarded as content gaps. In Item 2.4, only 35.48% ticked the correct answer (refer to Appendix E). Incorrect responses to this item confirms that participants lacked lot of knowledge of the topic they teach, since the question was extracted from 2014 grade 11 final question paper and could not be answered by most of the participants. Participants' insufficient and even incorrect scientific knowledge contribute to the underperformance of physical sciences results. It can be deduced that the physical sciences teachers had knowledge gaps and alternative conceptions and confusions with regard to electrodynamics.

Points discussed in part 3 of the questionnaire in 6.5.2, were all on applications of electromagnetic induction (electrodynamics). The results confirm that the participants had content gaps, confusion and alternative conceptions. The 'no attempt' option in the pre-test results (Table 6.11) was observed to have the highest percentage of all options and averaged above 50 %. The trend observed was that in all items, participants did not bother to give answers. In the participants' individual responses, 7 participants did not answer the whole Part 3 question, that is, not a single item was answered. Some participants even declared by writing in the space provided for answers that they, 'don't know' the answer. One other thing that was identified was that reasoning in this part was mostly illogic and concepts and terminology were mixed up when trying to support answers, with many more naïve ideas presented in reasoning. Basing on this summary, conclusion could be drawn that most participants do not have an adequate knowledge of electromagnetic induction. That was confirming that participants had content gaps, confusions and alternative conceptions. Since this part is a category on its own, it then supports statements that were summarising the category analysis in 6.3.2 that to know the structure of knowledge is to know the framework of concepts and laws in that category. In this case, it means that to understand the applications in electrodynamics it is to first understand the framework of concepts and laws of electromagnetic induction. Then to know the processes is to know where the knowledge comes from, how the framework is constructed and how it can be justified and applied.

The category of induction (category 3) was performed better than category 1 (sources of magnetic fields) and the expectation would have been the opposite. If category one and two was not well responded to, then the same expectation would

apply for induction category. The items in that category were extracted from the grade 12 topic (electrodynamics), hence there was performance. This performance can bear testimony to participants knowing the grade 12 curriculum, but not knowing the basic concepts (curriculum) from lower grades and these are the outcomes of rote learning and content gaps participants have.

Lenz's and Faraday's laws: These two laws were stated as difficult for participants to explain to learners in the participants' reflections before the intervention. From the pre-test results it was clear that the participants did not understand the laws themselves (refer to Item 2.4 in section 6.3.1 above) and were confusing the two laws.

Interpretation of a negative sign in the equation $E = - \frac{d\Phi}{dt}$ was noted in the participants' reflection as a challenge to the learners, this point is supported by questionnaire Item 2.10 in section 6.3.1 above. The negative sign represents the fact that according to Faraday's law a current is induced in the wire, which by Lenz's law; is in a direction such as to produce magnetic flux to resist the change in flux. Category 4 of 6.3.2 above supports the discussion that the participants contributed to the learners' incomprehension of concepts. The average of 18.55% confirms that the problem was from the participants' side. Refer to Appendix J, as an example of this line of how they expressed their problems and confusions in the video recordings. These results were further confirmed by poor performance discussed in category or Category 4 of 6.3.2. Induction is the centre or core knowledge of the understanding of electrodynamics taught by the participants / teachers in the FET syllabi; hence our participants find it difficult to explain to the learners. Transformers were also mentioned in the participant reflections as providing difficulties. This point still takes us back to the issue of categories. If electromagnetic induction is not well-understood, that creates a content gap for Faraday's law and then transformer as well. The results of the study indicated that the transformer had been stated as a difficult concept because of the participants' insufficient knowledge of induction. The next paragraph gives the analysis of part three results of the post-test.

Difference between a motor and a generator: The participants indicated this point as a challenge for the learners, but Item 3.1 of section 6.5.1 discussed above

indicates the participants are the ones who confused the learners. Incorrect information is being transmitted to the learners because the participants were confused about the two machines themselves. During intervention, the theory was emphasised for conceptual development and the sequence of concepts as it was explained also impacted positively. Difference between generator and motor was theoretically emphasised using drawings and examples to logically explain the difference (refer to Appendix J)

The topic of electrodynamics in general: Some participants admitted that the topic in general is the problem. Some of the reflections from participants would tell that they were clueless as to what knowledge to use. For example; some participants consider Coulomb law to be of central importance and core knowledge and completely disregard electromagnetic induction. A gap in one concept creates misunderstanding, confusions and alternative conceptions and eventually the whole topic becomes a challenge.

The following points were identified during the intervention since the whole process was video recorded to identify challenges in this study. The researchers identified that there were areas of deficiency in participants' knowledge structures during the intervention and the points were discussed in 6.5.1.2 above.

Comprehensive common alternative conceptions were concluded in this study as the persisting and common in electrodynamics and were addressed by considering the use of simulations and experiments as it was supported by the participants' feedback that they make abstract concepts easy and real.

6.9 SUMMARY

The chapter presented an analysis of the qualitative and qualitative data and the results thereof. The research questions were also answered in this chapter. The next chapter (Chapter 7) presents the findings in this study, the answers to the research questions, the conclusions and recommendations.

CHAPTER 7: FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This study was done by means of a literature review and empirical study and was a small-scale in-depth study done with physical sciences teachers of the North West Department of Education of South Africa. In this study, the focus was more on the conceptual development of electrodynamics. The literature reviewed the topic electrodynamics and its related concepts, and further reviewed different approaches to the teaching and learning of the concepts. A teaching sequence was implemented to enhance conceptual development of electrodynamics among the physical sciences teachers.

This chapter constitutes a summary of the study and aims to present the main findings, the concluding remarks as well as the recommendations that stems from the results of this study. The findings as well as the conclusions focused on the research questions and the objectives of this study, stated in section 1.3 and 1.4 of Chapter 1. Section 7.2 summarises the chapters of the dissertation, to give an overview and the scope for the research study. Then, section 7.3 and 7.4 give the findings and recommendations of the study respectively.

7.2 OVERVIEW OF THE STUDY

The participants' pre-conceived knowledge was explored to try to reconstruct, refine and improve their content knowledge in electrodynamics. The researcher intended to address the challenges that the participants had through a teaching sequence that infused practical work and computer simulation. Consequently, the research questions that guided this study were built around the aims and objectives reported in 1.3 and 1.4 in Chapter 1. Therefore, the aim of the study was; to investigate the impact of a teaching sequence using simulations and experiments on physical sciences teachers' conceptual development of electrodynamics. Hence the following research questions guided this study:

- What challenges do physical sciences teachers experience regarding electrodynamics and what are the underlying concepts can be designed?

- What teaching sequence comprising of computer simulations and practical work for conceptual development of electrodynamics can be designed.
- What impact will the designed teaching sequence have on the conceptual development and improvement of knowledge of electrodynamics among the physical sciences teachers?
- How can the derived subject-related learning principles for conceptual development be implemented in the teaching sequence for learning gain?

To answer the research questions, different strategies for conceptual development model were compared. The interactive teaching approach versus verbal traditional teaching approach were applied and evaluated. In view of the constructivist theory in a learner-centred teaching environment, interactive strategies such as computer simulations and practical work served the purpose for effective learning. The next section shows how this study was organised and presented into chapters.

7.3 SUMMARIES OF CHAPTERS

7.3.1 Chapter 1

Chapter 1 presented an introductory orientation of the study. A comprehensive motivation for the study was also given. It stated the research questions, aims and objectives of the study and the research method. Descriptions of terms related to electrodynamics were also included in this chapter.

7.3.2 Chapter 2

This chapter reported on the literature study, dealing with conceptual development in electrodynamics based on historical investigations and reasoning. An overview of the development of concepts in the FET syllabus (grade 10 to 12) including practical work was done. The historical development of electrodynamics was reviewed to get an overview of the role it played in the teaching and learning of electrodynamics and in the development of technology in the modern society.

7.3.3 Chapter 3

This chapter reviewed challenges in the learning of electrodynamics to form the basis for the investigation of teachers' conceptualisation, refer to objective 1.3.2.1 of

Chapter 1. The chapter was reviewed to study different challenges that prohibit learning as opposed to constructivist learning, with more focus on the existing alternative conceptions in electrodynamics.

7.3.4 Chapter 4

The chapter reviewed different teaching methods and instructional approaches for conceptual development in the constructivist teaching and learning of physical sciences. This review was done because the investigation conducted in this study focused on intervention strategies for effective teaching and learning of electrodynamics. Hence the researcher proposed the teaching sequence using simulations and practical work to improve knowledge and understanding of electrodynamics among the physical sciences teachers. Consequently, the research questions addressed in 1.4 of Chapter 1 guided this study.

7.3.5 Chapter 5

This chapter set out the research methodology followed in the execution of the empirical part of this study. The questionnaire, teacher reflections, the video recording and the evaluation form used as research tools were discussed. An outline of the method and procedure used in the empirical research was given. The chapter entailed the design and methodologies that were followed to answer the research questions and to achieve the objectives of the study as stated in 1.3 of Chapter 1. Specific reference was given to a mixed method approach that was used as the procedure for collecting and analysing quantitative and qualitative data to investigate the research problem.

7.3.6 Chapter 6

This chapter reported on the results of the empirical survey and a discussion of the results was given. The quantitative and qualitative results (data and its analysis) emanating from the research was presented and discussed. The analysis of the results was summarised in tables 6.3 – 6.8. The discussion of the results followed each table. The analysis helped to answer the research questions which guided this research (stated in Chapter 1, see paragraph 1.4). This chapter also summarised

common trends of alternative conceptions in electrodynamics and compared the concept developments that were discussed in this study

7.4 FINDINGS AND CONCLUSIONS

7.4.1 Research question 1

The first research question that guided this study was: *“what challenges do physical sciences teachers experienced regarding the conceptualisation of electrodynamics and the underlying concepts”*.

The results of the pre-test analysis revealed that most participants performed poorly when responding to the items of the questionnaire. The indication was that most participants did not have adequate knowledge of electromagnetic induction. Participants' alternative conceptions, confusions and conceptual difficulties were exposed as indicated in paragraph 6.3 of Chapter 6. The low percentage of correct response among participants, that is, below 50%, is a reason for concern, because the questions items were based on the physical sciences syllabus. The next sections present the highlights and general trends of the findings categorised per knowledge area.

Category 1: Sources of magnetic fields

The category indicated the general performance of participants' understanding of the sources of magnetic field. The general performance in this category was standing at 38.2%. Item 1.2d revealed that 93.6% of participants did not know that a steady current causes a magnetic field. This basic principle is expected to be answered by any grade 12 learner doing physical sciences and yet participants teaching the subject were unable to answer correctly. The performance poses a threat for the future of physical sciences learners in our schools.

Category 2: Magnetic field interaction:

Participants' positive responses to items of category 2 were below 30% with an overall of 18.6%. It is in this category where participants performed the worst. The participants' responses to this category are a confirmation that participants are challenged by the physical sciences curriculum. If the teachers' performance is at this level for the FET curriculum that they must teach, then one can hypothesise the problem and generalise to say we are faced with a challenge that needs to be addressed. There might be more physical sciences teachers out there who are struggling with basic principles of electromagnetism like the ones in the sample group.

The magnetic field interaction (category 2) prompted out a question on the earth magnetic field, which was a new concept in the physical sciences curriculum. The question was then raised that during the interaction of the magnetic field of a current and a bar magnet, the third magnetic field of the earth should also interact and the interaction should be of the three magnetic fields. The concept of the earth's magnetic field was not in the physical sciences curriculum when it was raised during the intervention. There were confusions and gaps about the concepts among all the participants.

Category 3: Induction

Participants performed better in category 3 than category 1. The expectation would have been the opposite because category one builds on category three and if the two categories indicated underperformance then the same was expected to apply for induction (category 3). This performance can bear testimony to traditional teaching and rote learning. The item in this category was from the grade 12 physical sciences topic. From my experience as physical sciences subject advisor, during the academic year, physical sciences teachers focus more on the completion of the syllabus to produce good end results. The participants master the grade 12 concepts to survive the pressure of accountability of poor performance which the department uses as a measure of teachers' performance. The records of grade 10 – 12 results can be sourced from any circuit office in North West Province of South Africa, with specific reference to Kgetleng circuit in Ngaka Modiri Molema district, as proof that

poor performance in lower grade is worse than in grade 12. The participants know grade 12 physical sciences curriculum better than any other grade, hence the grade 12 concepts are responded to better by the participants, as opposed to the basic knowledge (category 1 and 2) taught in grade 10 and 11. The topic progresses from category one to category three in the physical sciences syllabus, refer to Table 2.1 of FET syllabus. Better performance in this category did not guarantee meaningful learning and understanding.

General performance of participants in all the categories

The participants in all the categories performed below 40%, when the margin was 50% since the content of the research topic was based on the physical sciences curriculum, the curriculum which the participants are familiar with. The performance percentages per categories in an ascending order are presented in table 7.1 below:

Table 7.1: General performance per category

Category	Performance (%)
1	38.2
2	18.5
3	32.3
4	19.4

It can thus be deduced from the above table that participants did have alternative conceptions, confusions, content gaps and serious challenges in electrodynamics as it was addressed by objective of this study.

Comprehensive alternative conceptions: Findings of common alternative conceptions from the literature reviews (section 3.4.4) and this study (section 6.6) were identified and were considered as the major alternative conceptions. In this study, common trends of alternative conceptions were done by comparing the ones identified in this study and the ones identified from the literature review. An overall of six (6) comprehensive alternative conceptions were found to be the persisting common trend in electrodynamics. These findings automatically qualify such concepts or category to be alternative conceptions, confusions or content gaps (refer to objective 1 of this stud).

The deduction from the results of the pre-test was that the physical sciences participants had knowledge gaps, alternative conceptions and confusions with regard to electrodynamics. Their insufficient and even incorrect scientific knowledge contribute to the underperformance of physical sciences results.

7.4.2 Research question 2 and 3

The second research question that guided this study was: *“What teaching sequence comprising of computer simulations and practical work for conceptual development of electrodynamics can be designed?”* The research question 3 was: *“What impact will the designed teaching sequence have on the conceptual development and improvement of knowledge of electrodynamics among the physical sciences teachers?”*

Section 6.7 of Chapter 6 analysed concept development that occurred during the intervention. The conceptual development of the physical sciences syllabus was compared with the historical developments to serve as guidance for the concept development of this study. In the review of the historical development, it was found that progression of concepts was constructive. As one goes through the history, the bits and pieces were building constructively to form a whole. During the literature review of the physical sciences syllabus, it was found that FET syllabus may be a contributing factor to the content gaps that were necessary for the development of knowledge on electrodynamics. The physical sciences syllabus was stagnant and not in line with constructivist learning theory emphasised in the theoretical framework of this study. This implied gaps of concepts as opposed to progressive construction to form a unit. Alternative conceptions may be a consequence of such content gaps (refer to paragraph 1 of section 7.7.2 for recommendation).

In this study, the teaching sequence of electrodynamics was developed and was guided by the reviews of historical development and physical sciences curriculum. Electrodynamics was covered in detail to understand and to form a unit module. Network of concepts and their links to the umbrella topic progressed constructively in order to enable the learner not to just know the concept, but also to understand its context and relation to other basic concepts.

Another interesting finding that was revealed in this study was that the knowledge of electrodynamics of the control group after traditional method of teaching also improved. A possible reason for the enhanced performance was that the progression of concepts (conceptual development) in a traditional method was arranged in such a way that it impacted positively for knowledge improvement. Even when the two sampled groups were exposed to two different teaching strategies; both groups improved (refer to paragraph 3 of 7.5 above). There was a learning gain for the control group, but for the experimental group the performance was better than the control group (refer to Figure 6.5 in the analysis of results). Table 6.3 revealed that generally the experimental group outperformed the control group in all items of the test except for Item 2.3 and 2.9 that dealt with aspects in magnetic field interaction and induction respectively. For the experimental group, there was a remarkable improvement due to the teaching sequence and designed interactive strategies that was implemented.

Concluding remark for this research question was that a broad holistic approach should be followed in the teaching and learning of electrodynamics in the physical sciences syllabus. To enhance better understanding of concepts in physical sciences, it is important that concepts progress from simple basic knowledge to complex, abstract or unknown for conceptual development.

7.4.3 Research question 4

The forth research question that guided this study was: *“How can the derived subject-related learning principles for conceptual development be implemented in the teaching sequence for learning gain?”* How will the combination of experiments and computer simulations improve knowledge of electrodynamics?

The analysis of the results of the research question 1 indicated that participants possessed alternative conceptions and content gaps before intervention. Participants could not explain concepts and phenomenon until the teaching sequence was implemented. It is stated in this study (refer to section 2.4) that science is a practical subject that needs relevant methods and strategies for teaching and learning. The teaching sequence that was developed for intervention, infused experiments and simulations (refer to Appendix H and I) in the traditional method of teaching.

Participants' feedback on the teaching sequence emphasised the incorporation of simulations and practical work infused in teaching sequence to be having a positive impact on their learning gain. They maintained that types of workshops similar to the one used in this study was essential to help them to be successful in new and frequently intimidating situations they are faced with in the teaching career. Practical work and simulations incorporated in a teaching sequence can guide learners to constructive development of concepts for knowledge improvement in science teaching. The deduction from the evaluation form was that participants accept the use of experiments and computer simulations as the best method for conceptual development in science teaching and learning. The analysis of the video recording further confirmed that the activities and the approach increased conceptual understanding of experimental group during the intervention.

During the lessons participants were at most, observing, interacting by responding to questions or answering questions. They further discussed and reiterated electromagnetic concepts and processes with the help of the practical work and the computer simulations. Teachers displayed excitement as demonstrations of practical work and simulations brought concepts to life. Simulations and practical demonstrations complemented each other very well while teachers made inferences. An inference is an explanation of observation and may be based on the prior knowledge and experience. The teachers used what they know to explain what they were observing. The researcher then facilitated the discussions about the learners' inferences and summarized the key points (Ramnarain & Kiribige, 2010:17).

The participants' general comment made in the evaluation form was that the approach used during the intervention was the best and that it should at least be integrated within a teaching sequence for conceptual development. Specific general comments were that it makes teaching of physical sciences easier and saves time.

Conceptual development can be hard to accomplish and difficult to change existing or pre-conceived knowledge. To accomplish conceptual development towards correct scientific conceptions in a constructive way, learners' alternative conceptions need to be discredited to perceive the new concepts as believable, understandable and fruitful (Posner *et al.*, 1982).

Both Virtual Experimentation (VE) and Real Experimentation (RE) have gained the confidence of many researchers for their contribution to learning and instruction. The significance of the incorporation of RE and VE for conceptual development of content knowledge improvement, is making a difference (Zacharia, 2007:120-123). In this study, the impact of both VE (NTL) and RE (TL) in physics learning, was validated to be substantial when properly integrated within a physics curriculum, and mainly for the evolution of conceptual understanding. Comparatively, it was concluded that the data obtained from practical observations, irrespective of the type used, suggested better learning outcomes than pure traditional teaching and learning (Brinson, 2015:228). The concluding statement for this research question was that practical work and simulations incorporated in a teaching sequence can aid development of concepts in a constructive way for knowledge improvement.

7.4.4 Other findings

One other finding emanating from Chapter 2 of the literature review was that the structure of knowledge in the physical sciences syllabus was not in line with Bloom's taxonomy standard. The concepts and knowledge structure did not balance all cognitive levels and that compromised the quality of learning to a certain extent. The knowledge area in the syllabus covered and incorporated different cognitive levels but was not in line with Blooms taxonomy to teach all the skills. The cognitive levels in the syllabus did not address the demands of the subject, especially with regard to practical work. Practical work is one of the important strategies in physical sciences and requires that cognitive level for learning practical skills be emphasised. Expectation of distribution of knowledge areas and concepts should balance all cognitive levels and ensure that no content gaps occur. Framework and structure of knowledge in the syllabus should tally with the weightings on cognitive levels for assessment as per policy (DBE, 2011:144).

Other findings emanating from discussions during the intervention were that none of the teachers ever had a chance to conduct or observe experiments on electrodynamics at their respective schools. The experiment was never conducted due to lack of equipment at schools, and probably lack of confidence on the side of teachers as well. In this study, if teachers were afforded an opportunity to conduct experiment themselves, it would have meant that a new factor (different objective)

should have been introduced such that the researcher would focus on improving practical skills for the correct execution of the experiment. Since individual hands-on experimentation might have been a more effective approach than practical demonstrations, it is recommended for a follow-up study.

7.5 FINAL CONCLUSIONS OF THE STUDY

From the analysis of the data collected through the questionnaire, it was concluded that the teaching sequence using simulations and experiments had a positive impact for conceptual development and knowledge improvement. This study discredited the transmission method of learning and teaching to continue in physical sciences for the sake of better performance (Ausubel, 1968). This study was conducted in the constructivist learning theory, according to which learners gradually and progressively build new knowledge from existing knowledge. There was a significant learning gain *for the experimental group, because of the conceptual development teaching sequence. Practical work and computer simulations acted as the scaffolding which aided the participants to build their knowledge and understanding of the topic electromagnetism towards electrodynamics. Conceptual development for the topic progressed from simple to abstract; and all the basic concepts laid a good foundation for conceptual development to form a unit. Conceptual development was in such a way that content gaps, alternative conceptions or confusions were limited.

In this study, the impact of both practical demonstration and simulations in physics learning was validated to be substantial when properly integrated within a physics curriculum. The integration of the two strategies produced better learning outcomes than pure traditional teaching and learning. A concluding remark based on the improvement of the experimental group may strongly be attributed to practical demonstrations and computer simulations as an effective method of learning physical sciences.

7.6 LIMITATIONS AND CHALLENGES OF THE STUDY

The workshop was conducted for three days and there were too many activities that needed more time (say approximately a week). It was realised during the workshop (empirical study) that the time allocated for the workshop was not enough and for that reason, the researcher had to move faster to cover everything. During the empirical study, load shedding was also a problem in South Africa and the second day of the workshop load shedding was experienced for the whole day. It was very difficult to conduct a workshop for the whole day without electricity and we had to use hard copies that were organised before the workshop for presentation as load shedding was anticipated. For the presentation of simulations, the researcher had to move around the small groups to show the participants the simulations using a laptop and that limited the time even worse.

The number of participants for the sampling group was too small. With larger groups the statistical results would have been more reliable. The practical work was also conducted in a hall which limited the conduction of experiments. A science laboratory is the most useful space to conduct experiments.

The simulations used were not designed specifically for the South African curriculum, as there was no electrodynamics software that could be used to teach all the concepts at once. So, simulation software from PhET and you-tube in the teaching of electromagnetism were used in this study. The simulations that were relevant for electrodynamics were also insufficient and limited the researcher when selecting. Although a lot of time had to be spent to download and select appropriate software for the consolidation of the various concepts in electromagnetism, the workshop was a success.

7.7 RECOMMENDATIONS OF THE STUDY

It is envisaged that these recommendations would be helpful in alleviating problems associated with understanding and conceptualisation of electrodynamics. The research recommended that computer simulations and practical work be used for conceptual development in teaching sequences for knowledge improvement.

7.7.1 Recommendations for further research

Researchers should continue to find possible solutions to solve the problems facing physical sciences education. They should further promote a general awareness of the limitations of content knowledge to specifically address some of the more complex aspects of physical sciences, such as electromagnetic induction. Emphasis for further research was that historic development of content knowledge of any research topic in learning and teaching of physical sciences be reviewed for conceptual development. Another recommendation was to do further research on the quality and depth of skills teachers have on the execution of practical work, and to identify and attend to gaps that need to be improved in terms of practical.

In the teaching context of FET physical sciences, problems are continually observed and will carry on unless teachers' content problems or challenges are dealt with accordingly. It is recommended that similar research on different topics of physical sciences be executed. Common trends of alternative conceptions that were identified in this study remain to be a major challenge in the learning and teaching of physical sciences. Researchers should find ways to deal with this trend and find a way to address alternative conceptions in general. Conceptual development teaching sequence using practical observations or interactive strategies is recommended.

The outcomes of this research suggest that a combination of both real (TL) and virtual (NTL) experiments was fascinating and an important avenue of research. Zacharia (2007:129-130) and Brinson (2015) argued that much remained to be learned about the impact of combinations of TL and NTL in different domains and instructional contexts. Furthermore, the effectiveness of the two teaching methods tested in this study need to be evaluated. A question was provoked by findings in 7.4.3 on the retainment of knowledge after the two methods were implemented, hence the evaluation of the two methods. The researcher thus suggested sampling of the same group to test the retention of knowledge. Using the same group would save time to implement the teaching sequences before administering the same questionnaire that was used as the pre-post-test. Collections of data (post-post-test) only need to occur once in order to answer this recommended research question.

The results of this study were based on a small sample size of in-service physical sciences teachers. This study could also be used as the basis for further research of the same topic but in different contexts. Even if the context is different, the inferential results for the statistical methodologies employed in this study could be useful to replicate to schools, even to the learning of other challenging topics if they can be identified.

7.7.2 Recommendation for curriculum developers

It was also recommended that the curriculum developers review the historical development to guide the progression of the electrodynamics concepts in the FET syllabus. The historical development carried more weight than FET syllabus as it was progressing properly towards the understanding of electrodynamics. It is thus recommended that the progression of concepts towards the understanding of topics in the syllabus be guided by historical development where possible and relevant.

Curriculum designers also must ensure that the different cognitive levels are not only covered but distributed across each section to master all the skills and concepts. The spread of the cognitive levels should meet the demand of the subject to make the syllabus accurate and reliable. Syllabus coverage should provide a balanced well-rounded and good progression of the concept development for the understanding of concepts in the physical sciences. Syllabi should also assess performance at different cognitive levels with more weighting on process skills, critical thinking, scientific reasoning and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts.

Practical tasks/investigations or experiments are very important aspects of assessment in physical sciences in the FET Band. Practical aspects and the process skills required for scientific inquiry and problem solving are assessed. Thus, assessment activities developed by teachers should be designed so that learners are assessed on their use of scientific inquiry skills. Due to overarching importance of these skills in physical sciences, practical tasks to a large or considerable extent contribute to effective learning and teaching. Computer simulations can present concepts, experiments as well as examples of practical applications in industries and real life.

7.7.3 Recommendations for Department of Education

It is recommended that the in-service training to be organised for teachers who were already in the system. In this study teacher needs were identified from the sample group and could be used for purposes of teacher training for a larger group. Electrodynamics is one of the important and examinable topics in the Further Education and Training (FET) schools progressing from grade 10 to 12. An implication of this is that the problem could occur more generally and need attention. Under-performance of participants during the pre-test in the sample group should inform the department of the need to conduct the experimental workshop throughout the province.

Service providers should be drawn from the universities and should work in partnership with the department of education to provide in-service training to physical sciences teachers. School, universities and the department should constantly operate as a unit to keep abreast with aspects that affect the education system of the country, especially natural sciences teachers, who lay the foundation at the GET level. There should be a resolute effort to close the gap that exists between these stakeholders to improve the standard of physical sciences learning and teaching in South Africa.

In the department of basic education, there is a unit called Mathematics, Science and Technology Services (MSTS), which work in collaboration with the National Department of Science and Technology. On the bases of such, it is further recommended that the MSTS be redirected to equip the schools with physical sciences computer based software and provide training to the use of these in order to improve the physical sciences performance reported every year by the Department of Basic Education during the revelation of the grade 12 results.

Another recommendation to the department is the need for compulsory and supervised practical examination as one of the requirements for level or grade completion. The practical examination should be an additional requirement to pass the subject throughout the FET grades. The nature of this subject should be well-displayed and well-understood by science learners and be treated as the norm for the subject.

7.7.4 Recommendations for the teachers

It was recommended that electrodynamics in the physical sciences syllabus be introduced with the basic concepts, namely; electricity and magnetism (electromagnetism), and then electromagnetic induction as the heart of electrodynamics, followed by applications and everyday life example. It was further recommended that teachers infuse practical work and simulation as knowledge progress during conceptual development. The syllabus should also progress throughout the grades to form a unit module from which the teachers can teach with understanding.

From the experience of the researcher, many teachers are not willing to teach physical sciences, or if they do, they teach it in a way that does not meet the subject requirement. The researcher recommend that physical sciences teachers re-evaluate their method of teaching, specifically the traditional method of teaching that almost everybody seem to be comfortable with. The nature of the subject does not accommodate pure transmission. This necessitates the existence of an entity that will address the needs of the teachers to be able to perform best and maximally throughout their teaching careers. The entity refers to the physical sciences content and laboratory training workshops, and the necessity to take these workshops serious. Teachers should attend the workshops arranged for them to address challenges identified in the teaching and learning of physical sciences. Teachers should bear in mind that these workshops contribute to the improvement of knowledge and sharing of good practices relevant for learning and teaching of physical sciences.

7.7.5 Recommendations for tertiary institutions

The recommendation is made that the universities consider an additional module that can equip university students with the technology based skills that are appropriate for the teaching and learning of physical sciences. Such a module should be added as one of the fundamental subjects to equip the teachers with required knowledge and skills to handle computer-based teaching effectively before they graduate. The same goes for practical examination as a requirement for pre-service teachers enrolled at the universities. Teachers should go to the education

system being well-equipped to make a difference in the teaching and learning of physical sciences.

7.8 SUMMARY

The research study offered and provided modern ideas on how to effectively and progressively approach difficult concepts. The teaching sequence used in this study presented an approach and solutions for effective teaching and learning physical sciences. The impacts of computer simulations and practical work on the learning of the topic electromagnetism as it was displayed in this study had implications for researchers, teacher trainers, teachers, learners, institutions and the Department of Education. This study further contributed to literature in a way that it provides evidence that the use of computer simulations combined with practical work have significant effect in physical sciences learning if incorporated in a progressive conceptual development sequence. It also provided an alternative method to consider as an effective instructional model for constructivist learning approach and for lifelong learning.

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APPENDIX A: PERMISSION LETTER FROM DBE

	Education and Sport Development	
	Department of Education and Sport Development Departement van Onderwys en Sportontwikkeling Lefapha la Thuto le Tihabololo ya Metshameko NORTH WEST PROVINCE	275 Visser Street, Swartruggens 2635 Tel.: (014) 544-0606 e-mail: bmolokoe@nwp.gov.za

**OFFICE OF THE AREA MANAGER: KGETLENG AREA OFFICE
NGAKA MODIRI MOLEMA DISTRICT**

To: Ms M.J. Mabalane
Researcher: NWU

From: Dr B.K.M. Molokoe
Area Manager

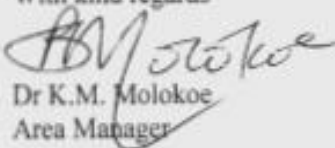
Date: 08 September 2015

Subject: **PERMISSION TO CONDUCT RESEARCH**

This letter serves to respond to your request for permission to conduct research in schools in Kgetleng River Area. Please be informed that permission is granted and that research activities will not disturb teaching and learning including the smooth running of the schools.

We wish you well and look forward to sharing your findings with us.

With kind regards


Dr K.M. Molokoe
Area Manager

DEPARTMENT OF EDUCATION KGETLENG RIVER AREA OFFICE TEL: 014 544 0606 F: 014 544 0346 2015-08-08 PRIVATE BAG X1003 SWARTRUGGENS NORTH WEST PROVINCE
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APPENDIX B: LETTER TO THE PHYSICAL SCIENCES TEACHER



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Date: APRIL 2015

Dear Educator

Request for participation in this research

I am currently registered as a PhD student at the North-West University, Potchefstroom Campus. My research focuses on **the impact of a teaching sequence on conceptual development of electrodynamics**, a topic on the FET syllabus. The attached questionnaire will enable me to gather your valuable input on the research topic. Authorisation for this research was approved by North-West Department of Education (see next page). Your area was selected to participate in this survey. I therefore kindly request your assistance in completing this questionnaire. The completion of the questionnaire will take you approximately 45 minutes.

*N. B: There is no harm to you as respondent in completing the questionnaire.

All information will be treated confidential.

Your identity will not be revealed

Every respondent and school will remain anonymous.

By completing the questionnaire, you agree to participate in this research on a voluntary basis.

Your participation is highly valued and appreciated.

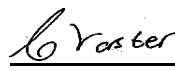
Kind regards

Mabalane M. J. (Researcher)

APPENDIX C: DECLARATION OF LANGUAGE EDITING

I, C Vorster (ID: 710924 0034 084), Language editor and Translator, and member of the South African Translators' Institute (SATI member number 1003172), herewith declare that I did the language editing of a thesis written by Mrs. MJ Mabalane (student no: 11700602)

Title of the thesis: The impact of a teaching sequence on teachers' conceptual development in electrodynamics

 9 June 2017

C Vorster Date

APPENDIX D: CONFIRMATION FROM STATISTICAL ANALYSIS



Private Bag X8001, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Web: <http://www.nwu.ac.za>

Statistical Consultation Services

Tel: 018 299-2018
Fax: 018 299- 2557
Email: wilma.breytenbach@nwu.ac.za

20 April 2017

To whom it may concern

RE: THESIS OF MS MABEL JULIA MABALANE (STUDENT NUMBER: 11700602)

We hereby confirm that the Statistical Consultation Services of the North-West University has analysed the data and assisted with the interpretation of the results of the thesis of Ms Mabel Julia Mabalane (student number:11700602).

Yours sincerely

A handwritten signature in cursive script, appearing to read 'Wilma Breytenbach'.

Wilma Breytenbach

MSc
Senior subject specialist

APPENDIX E: QUESTIONNAIRE

Complete the questionnaire by choosing the correct answer(s) of your choice and by giving a written response in the space provided.

SECTION A

Please provide the following information about yourself and your school:

1. Gender

1	2
Male	Female

2. Age in years

1	2	3	4	5	6	7
20 – 25 yrs	26 – 30 yrs	31 – 35 yrs	36 – 40 yrs	41 – 50 yrs	51 – 60 yrs	61+ yrs

3. Overall teaching experience in years

1	2	3	4	5	6	7
1yr	2 – 5 yrs	6 – 10 yrs	11 – 15 yrs	16 – 20 yrs	21 – 30 yrs	More than 30 yrs

4. Teaching experience as a Physical Sciences teacher in the FET band in years.

1	2	3	4	5	6	7
1yr	2 – 5 yrs	6 – 10 yrs	11 – 15 yrs	16 – 20 yrs	21 – 30 yrs	More than 30 yrs

5. Your highest teaching qualification

1	2	3	4	6
Diploma	Degree	Bed/Hons Degree	M. Degree	PhD degree

6. Your highest qualification in Physical Sciences/Physics/Chemistry

1	2	3	4	5	6	7
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1 st Year tertiary level	2 nd Year tertiary level	Diploma	Diploma + HED (ACE) / Degree	B Ed /Hons. Degree	Masters Degree	Doctors Degree
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7. Your position at your school

1	2	3	4
Teacher	Head of department	Deputy Principal	Principal

8. Location of your school

1	2
Rural	Urban

9. Is electricity available at your school?

1	2
YES	NO

10. Is running water available at your school?

1	2
YES	NO

11. For which grade/s do you teach Physical Sciences this year?

1	2	3
Grade 10	Grade 11	Grade 12

12. The highest number of Physical Sciences learners in any of your classes.

1	2	3	4	5	6
10 – 20	21- 30	31 – 40	41 - 50	51 – 60	61 – 70

13. Does your school have a science laboratory?

1	2
Yes	No

14. Do you have any kind of apparatus / equipment to do practical work (experiments) in your school?

1	2	3	4
WELL equipped	Moderately equipped	Only a few	None

15. Do you have any kind of ICT (e.g. computer software) in your school?

1	2
YES	NO

Do you own a computer?

1	2
YES	NO

Is a computer available for teaching in your school?

1	2
YES	NO

16. Which medium of instruction do you use to teach Physical Sciences at your school?

1	2	3	4	5
English	Afrikaans	Alternating between English & Afrikaans	Alternating between English & Setswana	One of the other official languages

For the majority of learners that you teach, the medium of instruction is their...,

1	2	3
Mother tongue	2 nd language	3 rd language

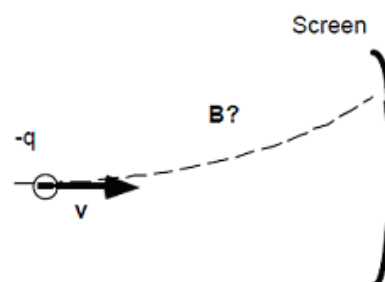
SECTION B

PART 1: ELECTRICITY AND MAGNETISM (BASICS OF ELECTROMAGNETISM)

Please check the box in front of each option and tick or colour the correct answer(s).

More than one answer may be correct.

1.1 An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. What is the direction of this magnetic field?



☐	a) Towards the top of the page
☐	b) Towards the bottom of the page
☐	c) Into the page
☒	d) Out of the page
☐	e) The magnetic field is in the direction of the curved path.

1.2 Which of the options below cause a *magnetic field*?

☒	f) a) A magnet
☐	g) b) A charge at rest
☒	h) c) A moving charge
☒	i) d) A steady current
☒	j) e) A changing current
☐	k) f) A magnetic field

1.3 Consider a compass, which points to the magnetic north pole of the earth. A number of objects are then brought near to the compass. Which of these can cause the compass needle to change direction?

X	a) A bar magnet
	b) A large charge at rest
X	c) A electric wire with a current
	d) None of these

1.4 A soft iron rod placed inside a current carrying solenoid

	e) a) Increases the electric and magnetic field strength produced by the solenoid.
	f) b) Increases the electric field strength in the solenoid.
	g) c) Decreases the magnetic field strength produced by the solenoid.
X	h) d) Increases the magnetic field strength produced by the solenoid.

1.5 Refer to figure 1 below. A positive charge Q is placed in a uniform magnetic field produced between two magnets.



Figure 1

	a) a) If stationary, the positive charge (Q) will be subjected to a magnetic force.
	b) b) If the positive charge (Q) is moving parallel to the uniform magnetic field (e.g. to the right in Figure 1 above) it will be subjected to a magnetic force.
	c) c) If the positive charge (Q) is moving parallel to the uniform magnetic

	field (e.g. to the left in Figure 1 above) it will be subjected to a magnetic force.
X	d) d) If the positive charge (Q) is moving perpendicular to the uniform magnetic field (e.g. upward in Figure 1) it will be subjected to a magnetic force.
X	e) e) If the positive charge (Q) is moving perpendicular to the uniform magnetic field (e.g. downward in Figure 1) it will be subjected to a magnetic force.

PART 2: ELECTROMAGNETIC INDUCTION

Multiple choice questions: circle the correct answer(s) for each question in this part.

2.1 A current carrying conductor placed in an external magnetic field experiences a force. The direction of the force experienced by the conductor depends on

- A. The direction of the current flow
- B. The switch
- C. c) The type of conductor used
- D. The strength of the magnet

2.2 Which of the following devices are based on the principles that a current carrying conductor in a magnetic field experiences a force?

- A. An AC generator
- B. A DC motor
- C. A coil
- D. An electromagnet

2.3 Which of the following will NOT affect the power output available from a particular AC generator?

- A. The strength of a magnet
- B. The number of turns in the coil
- C. The type of a natural energy source used
- D. The speed of rotation of the coil or magnet

2.4 The direction in which an induced current flows depends on

- A. Ohm's law
- B. Kirchhoff's law
- C. Lenz's law
- D. Faraday's law

2.5 Which of the following devices DOES NOT operate on the principle of induced EMF?

- A. An alternator
- B. A dynamo
- C. An AC generator
- D. An electromagnet

2.6 The magnitude of induced EMF depends on

- A. Rate of change of magnet flux with respect to time
- B. Rate of change of electric flux with respect to time
- C. Rate of change of voltage with respect to time
- D. Rate of change of induced current

2.7 How do you make an electromagnet?

- A. Connect a magnet to battery
- B. Run current through a wire wrapped around an iron rod
- C. Place a straight wire in a magnetic field
- D. Place a wire in a magnetic field with current flowing through it

2.8 What happens when you turn off current in an electromagnet?

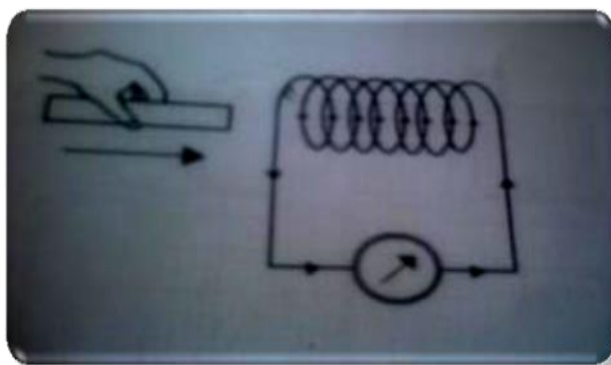
- A. The magnetic field reduces to zero

- B. The current keeps flowing because of the magnetic force
- C. The electromagnet loses its polarity
- D. The electromagnet becomes a generator

2.9 Which of the following inventions uses the generation of electricity from a magnet?

- A. A microphone
- B. A generator
- C. A galvanometer
- D. A motor

2.10 Consider the situation below and choose the relevant statement.



- A. South Pole is pushed into the coil
- B. North Pole is pushed out the coil
- C. North is pushed into the coil
- D. South Pole is pushed out the coil

PART 3: APPLICATIONS (MOTORS AND GENERATORS)

STRUCTURED QUESTIONS: LONG / OPEN ENDED QUESTIONS

3.1 Give two differences between the operation of a motor and a generator

3.2 Why is an AC generator used at power stations and not a DC generator?

3.3 Is the current at our home dwelling AC or DC? Motivate your answer by giving examples at home.

3.4 One of the applications of a generator is found in power stations. Briefly describe or explain the operation of the generator at a coal fired power station. Also include at least one function of the important parts (Coal, water, turbines) of a coal fired power station in your explanation.

APPENDIX F: EVALUATION FORM

QUESTION	Yes	NO	COMMENT
Was the whole workshop well organised and the facilitator well prepared?			
Did the workshop meet your expectations?			
Did the work-shop address challenges and misconceptions that were discussed earlier about Electrodynamics (in the group work activity)?			
Do you think the participants engaged well in the workshop? Why?			

What did you enjoy most?

.....

.....

.....

What do you think the facilitators could have done better?

.....

.....

.....

What would you suggest needs to be improved?

.....

.....

.....

Comment on the impact of experiments and simulations on your understanding of electrodynamics. (Be as specific as possible)

.....

.....

APPENDIX G: LESSON PRESENTATION

Electromagnetism and Electrodynamics Electromagnetism is the study of the properties of and relationships between electric current and magnetic field(Electrodynamics)	Magnetic Force Magnetic Force • Magnetic poles produce magnetic forces. • Can repel and attract without touching depending on which ends of the magnets are held near one another • All magnets have a north pole (end that points “northward”) south pole (end that points “southward”)
Magnetic Fields Magnetic fields: Force around a magnet The shape of a field is revealed by magnetic field lines that lead out from one pole, curve around the magnet, and return to the other pole. Lines closer together $\square$ field strength is greater The strength of a magnet depends on the number of magnetic domains that are aligned. The magnetic field is usually illustrated with the aid of a model.	Current • Charge (Q) is a fundamental particle of electricity and magnetism • Electric field (E) is part of a charge (just like mass of object), charge always have electric field, whether moving or stationary. • Stationary charges only have electric fields, force produced by a charges, hence ($F_E = KQq/r^2$), force is not aligned.

SOURCES OF ELECTRIC AND MAGNETIC FIELDS

Correspondences between electric and magnetic fields:

- Both fields exert attractive and repulsive forces, i.e. like repel and unlike attract.
- Both fields are created by charges.

BUT there are important differences between the two types of fields.

- ALL electric charges have electric fields.
- Only MOVING electric charges have a magnetic field (perpendicular to the direction of motion).

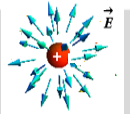
SOURCES OF ELECTRIC AND MAGNETIC FIELDS

- An electric field only interacts with other electric fields.
- A magnetic field only interacts with other magnetic fields.
- Electric and magnetic fields do not interact with each other.

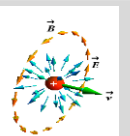
SOURCES OF ELECTRIC AND MAGNETIC FIELDS

NOTE: An electric current consists of charges moving in the same direction. We therefore observe a magnetic field around a current carrying conductor.

EVERY charge has a 3D electric field around it.



A MOVING charge also has a magnetic field perpendicular to its motion.



CORE KNOWLEDGE:

Moving charges produce magnetic fields perpendicular to their direction of motion.

Electric Currents and Magnetic Fields

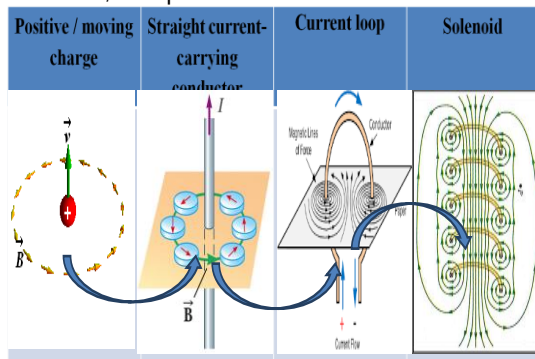
- A magnetic field is produced by the motion of electric charge.
- When a current flows in a single conductor or a coil, a magnetic field is **induced** by the current
- Magnetic field, symbolised by B is measured in Tesla (T).

CORE KNOWLEDGE:

Electromagnetism is the name given to magnetism that is developed by electricity (moving charges).

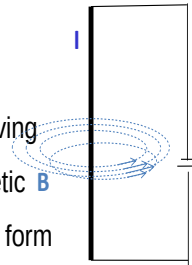
Electric Currents and Magnetic Fields

The sketches in the table below illustrate how the magnetic field patterns are formed in a straight conductor, a loop and a solenoid.



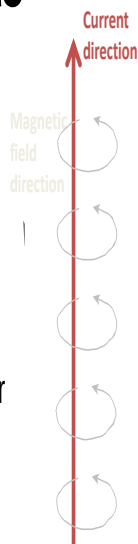
Currents and Magnetic Fields: Single conductor

A current consists of charges moving in the same direction. The magnetic fields of all the individual charges form the observed magnetic field around the wire, a circular magnetic field (concentric circles).



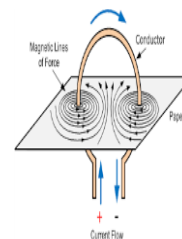
Currents and Magnetic Fields: Single conductor

- To work out the direction of the magnetic field in a conductor, use the "right-hand rule"
- Curl the fingers of your right hand, and point your thumb out straight. With your thumb pointing in the direction of the current flow, your curled fingers will be pointing in the direction of the magnetic



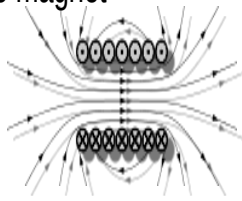
Currents and Magnetic Fields: A Loop or parallel conductors

- On the flat surface, two currents move in opposite directions in the loop. The magnetic fields of the two currents combine.



Currents and Magnetic Fields: Current carrying solenoid

- A solenoid consists of a number of current loops and the magnetic fields of all the **current loops** combine.
- A magnetic field surrounding a current-solenoid makes pattern of a magnetic field around the magnet



Electromagnets

- An electromagnet is a conductor which becomes magnetic when there is current flowing around it
- Not all substances can be magnetised easily nor do all substances lose their magnetism equally easily
- Some substances like iron, are easily magnetised and demagnetised, and these are referred to as soft magnetic materials

WB:Experiment 2

Electromagnets

- Others substances like steel are difficult to magnetise but retain the magnetism longer, and are referred to as hard magnetic material
- Strength of the magnets depends on:
 - Current in a conductor
 - Number of turns around the core
 - Type of substance used in the core

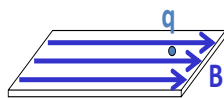
Electromagnets

- Electromagnets come in a variety of sizes, shapes and strength, and used in variety of appliances. Some uses include:
 - Lifting magnets
 - Electric bells
 - Relays
 - Loud speakers
 - Telephone receivers
 - Tape and video recorders

Interactions between magnetic fields

When magnetic fields of different sources are in the vicinity of each other they interact. The interactions result in a force that causes motion.

Force on a charge moving in a magnetic field

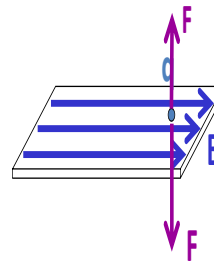


When a charge q is moving **parallel** to magnetic field B

- no force on q

Interactions between magnetic fields

Force on a charge moving in a magnetic field



When a charge q is moving **perpendicular** to magnetic field B

- There is a force on q

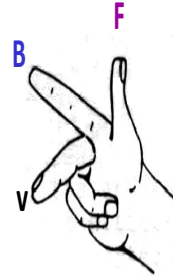
Charged particle(s) moving in a magnetic field experience a deflecting force—greatest when moving at right angles to magnetic field lines.

Interactions between magnetic fields

- Interactions between the magnetic field of the bar magnet and of a moving charges in the conductor give rise to a *magnetic force* that results in the *movement of the charge*.
- Moving charges(q) with a velocity (v) moving in a magnetic field (B), interact / combine, and the equation to calculate the magnitude of the magnetic force is given by ($F_B = qVB$)

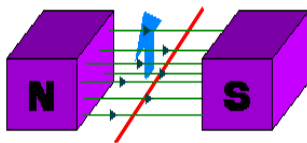
Interactions between magnetic fields

- Direction of motion of a moving charge(s) / conductor: *Left hand rule*:
 - middle finger = direction of the magnetic field (B)
 - index finger = direction of the velocity of the charge (v)
 - thumb = direction of the force (F).
- The electric field, current and force are all mutually at right angle



Magnetic Forces on Moving Charges

- Interaction between the magnetic fields of a straight current-carrying conductor and the field of a magnet:

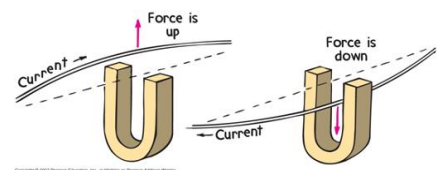


Interactions between the two magnetic field give rise to a magnetic force that results in the movement of the conductor. According to Fleming's left hand rule, the conductor in the sketch above will move **upwards**.

Magnetic Forces on Moving Charges

Magnetic forces on current-carrying wires

- A current of charged particles moving through a magnetic field experiences a deflecting force. If the particles are deflected while moving inside a wire, the wire is also deflected.

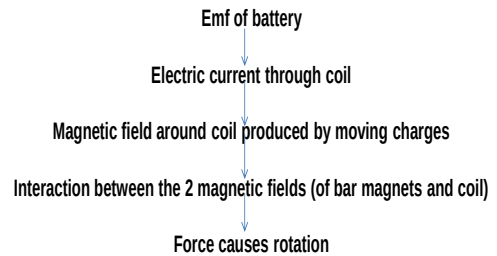


The electric motor

- The motion of a current-carrying conductor in a magnetic field is called the **motor effect**
- The electric motor uses the motor effect.
- The electric motor consists of a rectangular coil of wire placed between 2 permanent magnets. The current flows in opposite directions in the left and right hand sides of the coil. The forces F_{left} and F_{right} produce a torque on the coil, causing it to rotate, hence the motor turns.

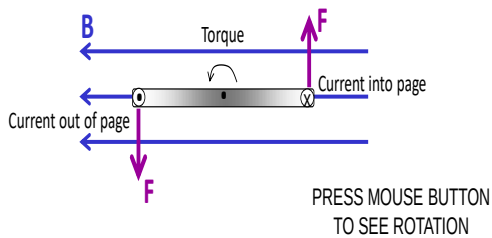
The electric motor

- In order for the coil to rotate continuously in the same direction, the coil is soldered to a copper split ring known as commutator. 2 carbon brushes are held against the commutator. The function of the **commutator** is to **change the direction of the current in the coil** and hence change the direction of the couple (the 2 forces in opposite direction) in every half revolution. How does an electric motor work?



The Electric Motor

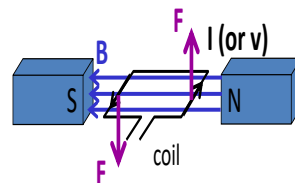
- This force causes a torque in the coil, and the coil rotates:



- o The electric motor therefore changes electrical energy into mechanical energy

The Electric Motor

Current I travels through a coil in a magnetic field B :

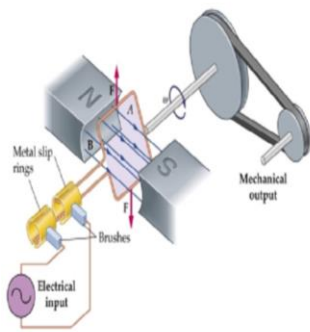


Here the current direction I tells us the direction of the velocity (v) of the charges.

Using the right-hand rule, the force F in the right hand branch is up, and in the left hand branch is down.



The Electric Motor



- An electric current causes the coil of a motor to rotate and deliver mechanical work to the outside world.

Outside world refers to appliances in the comfort of our homes; like Fans, Driller, Blender, washing machines, lawn mowers, etc. Demonstration: Motor: Experiment 3

Electric Currents and Magnetic Fields

Just as electricity may be harnessed to produce magnetism, magnetism may also be harnessed to produce electricity. The latter process is known as electromagnetic induction

Electric Currents and Magnetic Fields

- Electromagnetic induction is the complementary phenomenon to electromagnetism.
- Instead of producing a magnetic field from electricity, we produce electricity from a magnetic field.
- There is one important difference, though: whereas electromagnetism produces a steady magnetic field from a steady electric current, electromagnetic induction requires motion between the magnet and the coil to produce a voltage.

Electric Currents and Magnetic Fields

- If the magnet is moved relative to the coil, and electric current is induced in the circuit, the process is called electromagnetic induction.
- The induced current flows only when the magnetic field moves relative to the solenoid, i.e. when there is a change in magnetic flux linkage with the solenoid.

Electric Currents and Magnetic Fields

- The magnetic flux linkage, Φ , is given by

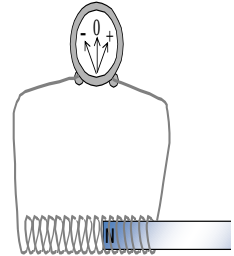
$$\Phi = BA$$

Where B is the magnetic field strength over a area A

Electromagnetic Induction

Creating a current using a magnet

- We can induce a current by moving a magnet inside a coil or vice versa.
- This is called [electromagnetic induction](#). (coil)
- A current can only be induced by a changing magnetic field.
- If the magnet remains in one position inside the coil, no current will be induced.

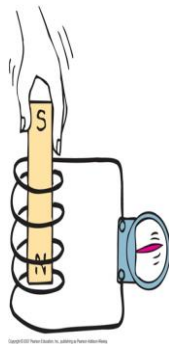


Electromagnetic Induction

Voltage is induced by the relative motion between a wire and a magnetic field. Whether it moves near a stationary conductor or vice versa, voltage is induced either way.

- The greater number of loops of wire moving in the magnetic field, the greater the induced voltage.

- Pushing a magnet at the same speed into a coil with twice as many loops induces twice as much voltage.



Electromagnetic Induction

- The emf ϵ induced in a coil is proportional to:
 - The number of loops in the coil, n
 - The rate at which the magnetic flux ϕ changes in the loops
 - In other words: The faster you plunge a magnet through a coil, the greater the [induced emf](#)
- Equations:

Faraday: $\epsilon = \Delta\phi / \Delta t$ OR $\epsilon = \Delta BA / \epsilon = -N \frac{\Delta\Phi_B}{\Delta t} \Delta\phi / \Delta t \cdot \cos \theta$

Lenz determine the direction of current:

$$\epsilon = -N \frac{\Delta\Phi_B}{\Delta t}$$

Electromagnetic Induction

Faradays Law

If the magnetic flux through a loop of wire changes for any reason either by changing the area, A , of the loop or the field, B , through the loop

Then an EMF (voltage) will be induced in the wire. This voltage will cause a current to flow (the induced current in the loop).

Faraday quantified the size of the induced voltage:

$$\mathcal{E} = -N \frac{\Delta\Phi}{\Delta t}$$

Electromagnetic Induction

Lenz's Law

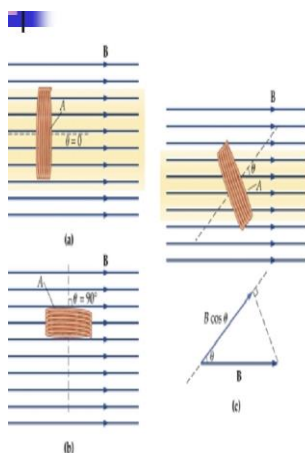
The current that is induced in a coil (due to a magnetic flux change through the coil) will always be such that it opposes the change that caused it.

Put another way:

Any induced current in a coil will result in a magnetic flux that is opposite to the original *changing* flux.

This is the origin of the negative sign in Faradays Law

Electromagnetic Induction



Magnetic Flux is continually changing as coil rotates.

- The magnetic flux through a loop of area A is $\Phi = BA \cos \eta$, where η is the angle between the normal to the loop and the magnetic field. (a) The loop is perpendicular to the field; hence, $\eta = 0$, and $\Phi = BA$. (b) The loop is parallel to the field; therefore, $\eta = 90^\circ$ and $\Phi = 0$. (c) For a general angle η the component of the field that is perpendicular to the loop is $B \cos \eta$; hence, the flux is $\Phi = BA \cos \eta$.

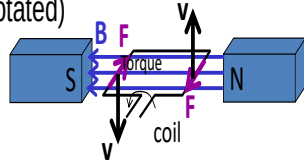
Application of Electrodynamics

- A *generator* can be used to generate voltage to turn a *motor*. This is an example of energy conversion from mechanical to electrical energy and then back to mechanical energy. As the *motor* is turning, it also acts as a *generator* and generates a "back emf".

Electromagnetic Induction:

The Generator

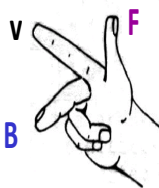
A coil is rotated in a magnetic field B : (or [magnet can](#) be rotated)



Here the movement of the coil tells us the direction of the velocity (v) of the charges.

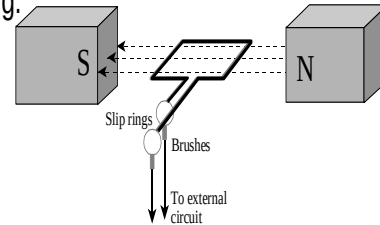
Using the right-hand rule, the force F in the right hand branch is outward, and in the left hand branch is inward.

This tells us the direction of the induced current.



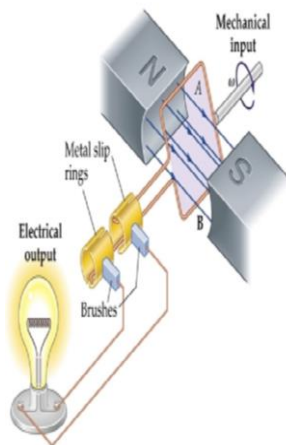
Current from a generator

- The two ends of the coil are attached to a slip ring.



- This makes contact with metal brushes as it turns, which are connected to the external circuit.
- When this coil is continuously rotated in the magnetic field, an [alternating current \(AC\)](#) is set up

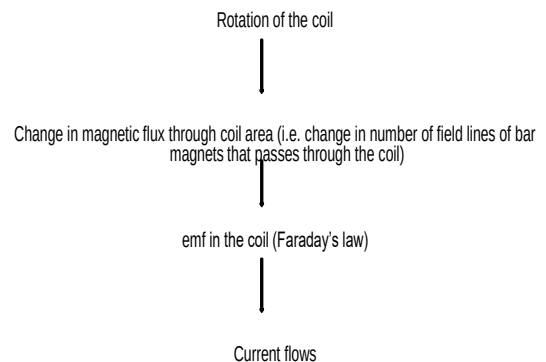
Current from a generator



- The basic operating elements of an electric generator are shown in a schematic representation. As the coil is rotated by an external source of mechanical work it produces an emf that can be used to power an electrical circuit.

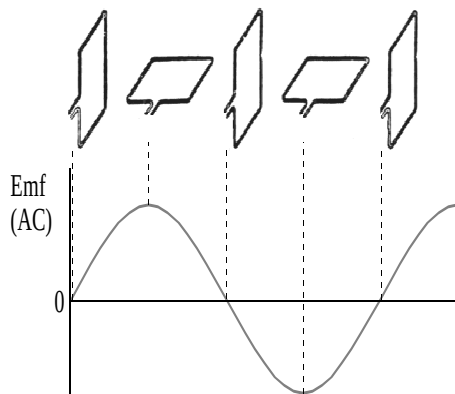
Electromagnetic Induction: The Generator

How does the generator work?



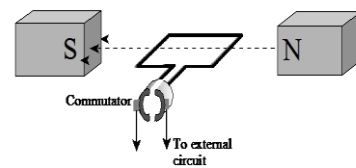
(W/B: Experiment 4)

Current from a AC generator

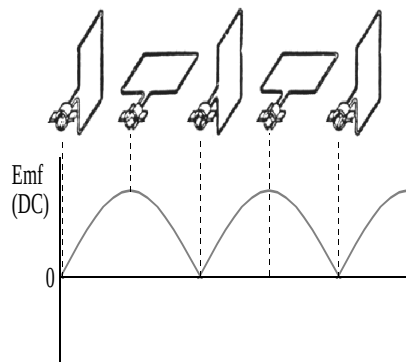


DC Generator

- Generators can also be used to create DC current.
- Here, whenever the coil is producing a negative voltage, we need to reverse the direction of the voltage so that it stays positive.
- To do this, the DC generator's slip ring is separated into two parts which do not make electrical contact with each other. This is now called a commutator.



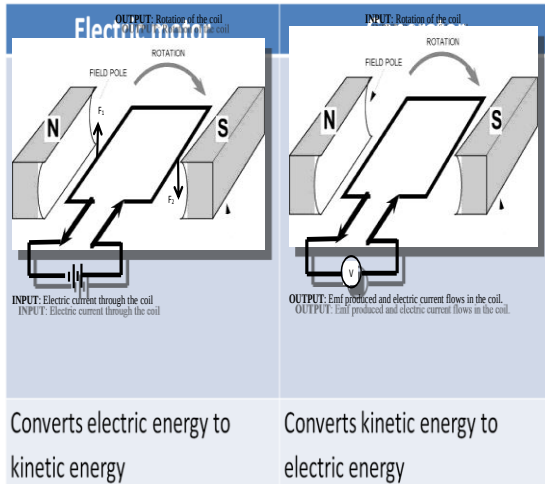
Emf from a DC Generator



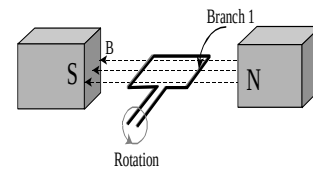
When are DC generators used?

- As a power source for electrochemical processes, such as charging of batteries and electroplating
- As a power source for electric trains
- As a power source for UPS's (power supplies for computers, designed to take over when the mains supply cuts out)

Comparison between Electric motor and a generator



2. The diagram shows a basic generator.

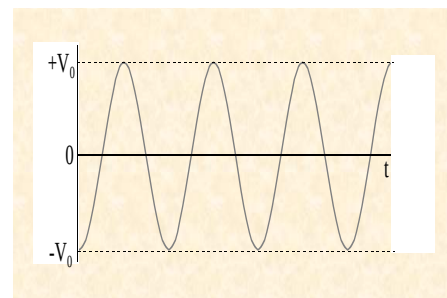


- Explain the difference between a generator and a motor.
- The loop in the diagram is rotating in an anti-clockwise direction. Is the current in Branch 1 travelling toward you or away from you? Explain your answer.
- What change would you make to this generator to turn it into a DC generator?

AC Electricity

- Advantages:
 - We are only able to use transformers with AC electricity, and transformers are very important for transporting high voltages of electricity (Transformers require a **changing magnetic field** to induce a voltage in the secondary coil. So a varying voltage in the primary coil is needed.)

- The graph of voltage versus time for AC is a sin wave:

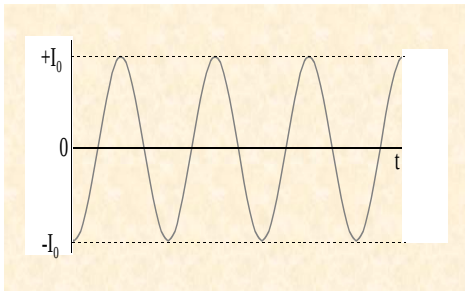


The voltage can therefore be expressed as:

$$V = V_0 \sin 2\pi ft$$

- From Ohm's law, we know that $V=RI$, so we can write an expression for the current in an AC circuit:

$$I = V/R = V_0/R \sin 2\pi ft = I_0 \sin 2\pi ft$$



RMS Values

- In AC circuits, a more useful way of expressing the current and voltage are in terms of their **root mean square (rms)** values:

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

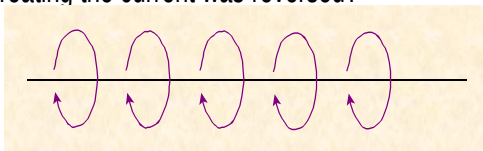
- These rms values are important, because these are the values that we use when calculating the average power dissipated in an AC circuit:

$$\bar{P} = I_{\text{rms}} \cdot V_{\text{rms}}$$

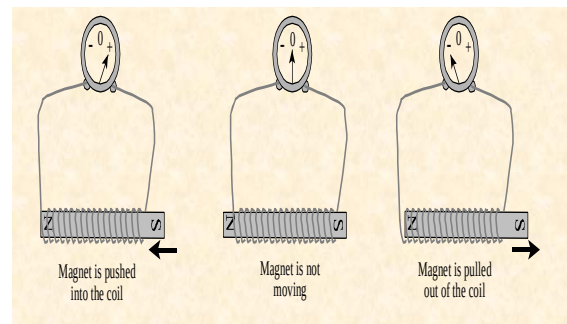
Example problems

- The diagram below shows the magnetic field lines around a current-carrying wire.

- What is the direction of the current in the wire?
- How would this diagram change if the battery creating the current was reversed?



- Explain what is happening in the diagrams below: [Electromagnetic Induction](#)



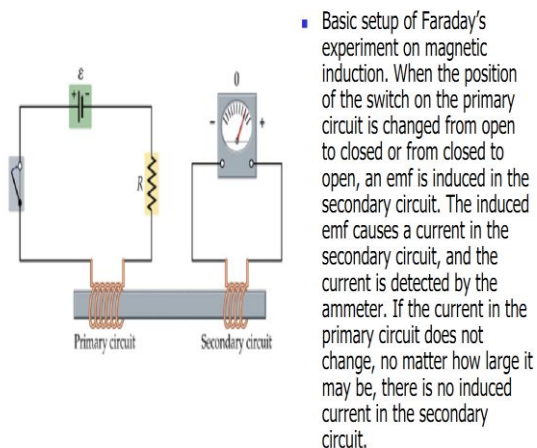
Mutual Induction

- When current is available, a changing current carrying a coil can be used to provide a change in magnetic field, which is necessary for inducing another current in the second conductor (coil), the phenomenon is called mutual induction.

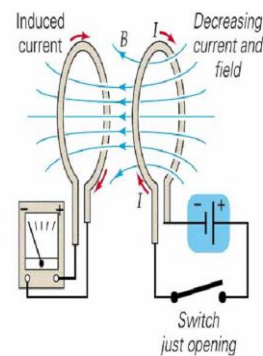
Mutual Induction

- The coil in which there was a deliberate a change in the current and magnetic field is called the primary coil and the coil from which there was a induced current is called the secondary coil.
- This is the principle of a transformer

Application of Mutual induction: Transformer

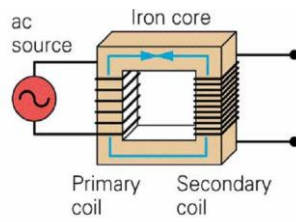


Application of Mutual induction: Transformer



If the source is AC then the field from the loop will continually change. So an AC current will be induced in coil 2.

Application of Mutual induction: Transformer



(a) Step-up transformer:
high-voltage
(low-current) output

$$N_S > N_P \Rightarrow V_S > V_P \Rightarrow I_P > I_S$$

Application of Mutual induction: Transformer

TRANSFORMER:

- In primary:

Emf of AC battery

Changing E-field in solenoid

Changing B-field in core

- In secondary:

Changing B-field is transferred from the primary to secondary core

Changing E-field in secondary coil

Emf (voltage) and current

W/B experiment 5

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

APPENDIX H: EXPERIMENT WORK BOOK

1. ELECTRICITY AND MAGNETISM

EXPERIMENT 1

AIM: TO INVESTIGATE THE MAGNETIC FIELD SURROUNDING A STRAIGHT CONDUCTOR, A LOOP AND A SOLENOID

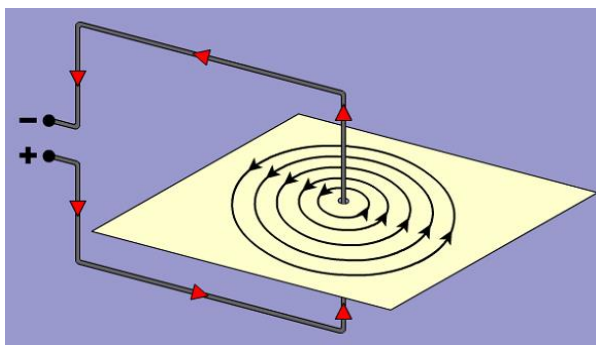
APPARATUS

Power supply (4 volts)	Iron filling
4 mm plug leads	Cardboard
Plotting compasses	Straight wire
	Loop and
	a Solenoid

METHOD

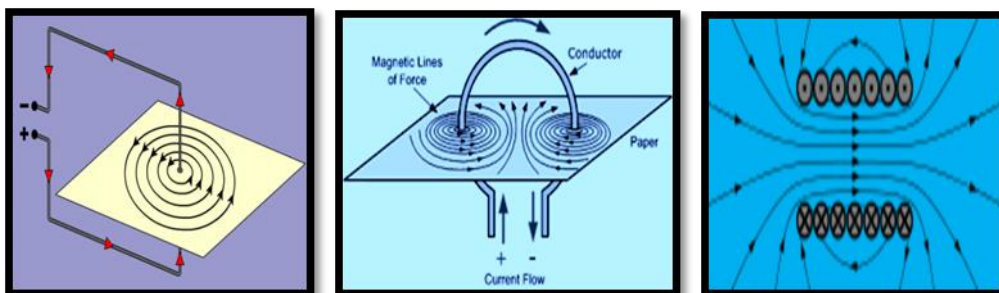
PART A

1. Push the conductor through a horizontally held cardboard as shown in the sketch below
2. Connect the wire in series to a battery and a switch
3. Sprinkle iron filings on the cardboard around the wire and switch the current on
4. Tap the cardboard gently and switch the current off when a clear pattern can be seen
5. Remove the iron filings and place a number of compasses on the cardboard around the wire and switch the current on again
6. Reverse the direction of the current and note the changes of the compass needle.



PART B

7. Set the apparatus as shown below
8. Use the plotting compasses to plot the direction of the magnetic field
9. Check your magnetic field pattern with the iron filings



OBSERVATION AND RESULTS

1. What is the form of the pattern of the iron filings around the wire when the current is switched on

2. Will there be any change in the form (pattern) of the iron filings around the wire when the direction of current is reversed?

3. Which pattern is formed by the compass needles when the current is switched on?

4. Do the iron filings which are further away from the wire also form a definite pattern like those which are close to the wire?

5. What conclusion can you make about the strength of the magnetic field around the conductor?

CONCLUSION

CORE KNOWLEDGE

The current consist of moving charged. The moving charges in the current-carrying conductors produce a magnetic field around the conductors.

EXPERIMENT 2

PART A: THE ELECTROMAGNET

AIM: TO INVESTIGATE THE RELATIONSHIP BETWEEN ELECTRICITY AND MAGNETISM (MAGNETIC FIELD)

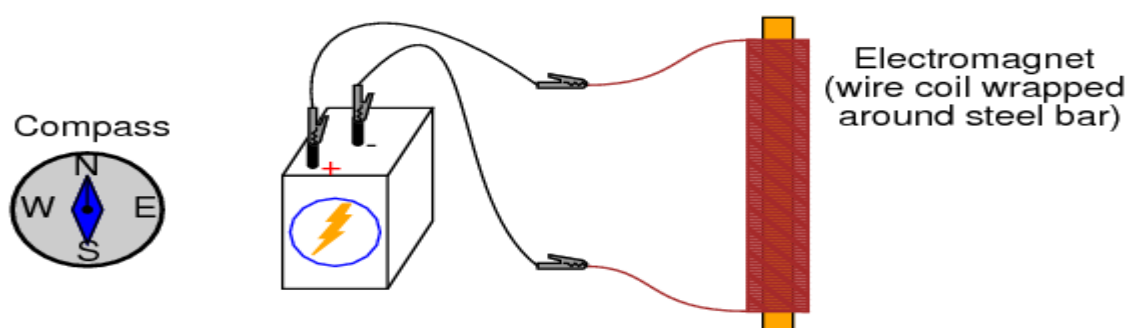
APPARATUS

300, 600 and 1200 turn coil	4 mm plug leads (conductors)
Iron core	Rubber wedge
DC supply (2 V, 4 V, 6 V and 8 V)	600 ml plastic container with pins or nails

Precaution: Use the rubber wedge to secure the iron core inside the coil as shown

METHOD:

Set up the apparatus as show below.



CONDUCTION AND OBSERVATION

1. Put an iron core inside the coil. Connect the coil to a 6 V DC supply and switch on current. Hold the iron core inside the coil over the beaker of nails then switch off the supply.

- Write your observation.

2. Use the magnetic compass to identify the "North" and "South" poles of the electromagnet.

- Observe the direction at which the needle is pointing and conclude.

3. Place a permanent magnet near one pole and note whether there is an attractive or repulsive force and / or note the difference in force (weak or strong).

- Write your observation?

CONCLUSION

When electric current goes through the coil, it will produce a strong magnetic field: one "pole" at each end of the rod. This phenomenon is known as electromagnetism. The magnetic compass is used to identify the "North" and "South" poles of the electromagnet.

Note that the magnetic field only exists when the current flows, i.e. when charges move.

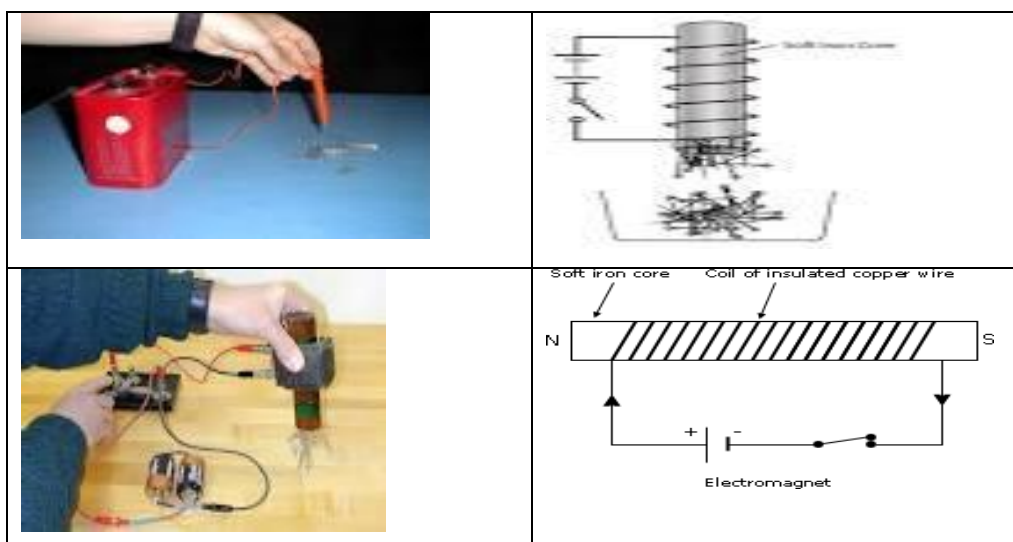
PART B: FACTORS AFFECTING THE MAGNETIC FIELD STRENGTH

AIM: TO INVESTIGATE HOW THE NUMBER OF TURNS AND CURRENT STRENGTH AFFECT THE STRENGTH OF THE MAGNETIC FIELD.

METHOD

Set up the apparatus as show below

Observations?	Formal diagrams
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4. Repeat step 1 in part A but only change the coil by increasing the number of turns.
5. Repeat step 1 in part A again but increase the voltage supply.

RESULTS AND / OBERVATION

1. Record your observations in step 4.

2. Record your observations in Step 5.

DATA

Current (I in mA)	0	2	4	6	8
Number of pins (resembles magnetic field strength B)					

GRAPH: Label the axis and indicate values in the graph



3. Write the relationship between a current and a magnetic field in words

CONCLUSION

EQUATION (Refer and compare to the findings)

EXPERIMENT 3: MOTOR

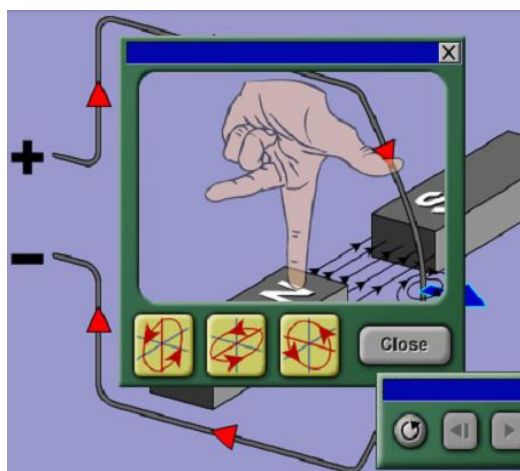
AIM: TO VERIFY THAT THE CURRENT CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD EXPERIENCE A FORCE

APPARATUS

DC power source	Magnets
Loop	conductors

METHOD

Set up the apparatus as shown below



The direction of this force can be determined using Fleming's Left Hand Motor Rule.

OBSERVATION AND RECORDINGS

Do the following and each time record your observation?

1. Connect the 4 V DC power source to the coil, and put the coil between the two strong magnets as shown above. The coil might require a little push at first to give it a momentum.

Observation:

2. Increase the voltage from 4 V to 6 V/8 V and repeat the action in step 1

Observation:

3. Use a stronger magnet and repeat the action in Step 1.

Observation:

4. Increase the number of turns of the solenoid and repeat the action in Step 1.

Observation

CONCLUSIONS

NOTE: The force is due to the interaction of the magnetic field between the bar magnets and the magnetic field between the bar magnets and the magnetic field around the conductors. (Magnetic fields only interact with other magnetic fields).

EXPERIMENT 4

CORE KNOWLEDGE: electromagnetic induction requires motion between the magnet and the coil to produce a voltage.

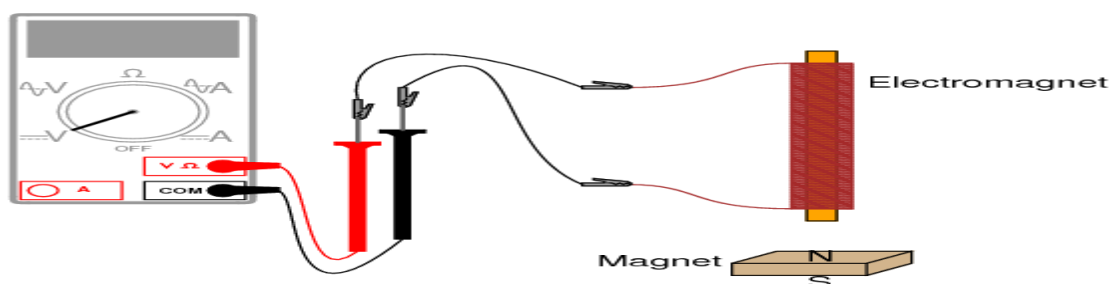
AIM: TO INVESTIGATE THE RELATIONSHIP BETWEEN MAGNETIC FIELD STRENGTH AND INDUCED VOLTAGE

APPARATUS

Coil	Bar magnet
Steel bar	Connecting wires
Multimeter	

PRECAUTION: If using an analogue meter (use lowest scale), and be sure to use long jumper wires and locate the meter far away from the coil, as the magnetic field from the permanent magnet may affect the meter's operation and produce false readings. Digital meters are unaffected by magnetic fields.

METHOD AND OBSERVATIONS



Do the following and each time record your observation?

1. Connect the multi-meter to the coil, and set it to the most sensitive DC voltage range available. Move the magnet slowly to and from one end of the electromagnet, noting the polarity and magnitude of the induced voltage. Try the other end of the permanent magnet and compare to your first observation.

2. Move the magnet to and from one end of the coil, this time faster.

3. Use a stronger magnet (can use two magnets combined) and repeat the above action.

4. Increase the number of turns of the solenoid and repeat the above action.

DISCUSSION AND CONCLUSION

Draw a conclusion from the above observations, stating and defining the name of the phenomenon observed.

Step 1

Step 2-4

Name and State the Law that can be used to determine the direction of the induced current (as a result of the induced EMF).

EXPERIMENT 5: GENERATOR: POWER STATION APPLICATION

AIM: TO VERIFY THAT AS THE COIL IS ROTATED BY AN EXTERNAL SOURCE OF MECHANICAL WORK IT PRODUCES AN EMF THAT CAN BE USED TO POWER AN ELECTRICAL CIRCUIT.

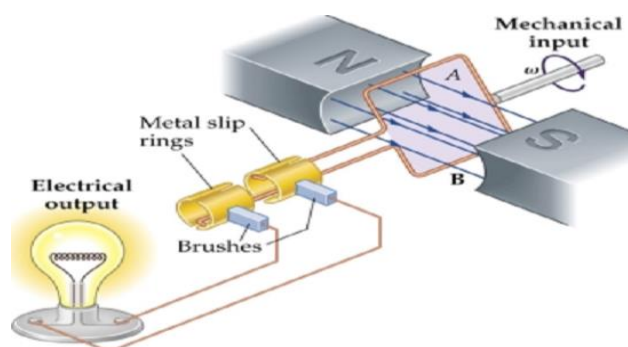
APPARATUS

Generator kit	Wax and coal
Bulb / galvanometer	Water

METHOD

Set up the apparatus as shown below.

Coal will be burned to boil the water that will produce steam that will turn the wheel (an external source of mechanical work) to induce an EMF.



The direction of this current can be determined using Right Hand Rule.

OBSERVATION AND RECORDING

CONCLUSSION

EXPERIMENT 6: TRANSFORMER

AIM: INVESTIGATING THE PRINCIPLE OF AN AC TRANSFORMER

APPARATUS

- At least 4 x 1,5 V cells (a DC power supply)
- 2 solenoids
- AC voltmeter (with negative and positive scale)
- Wires

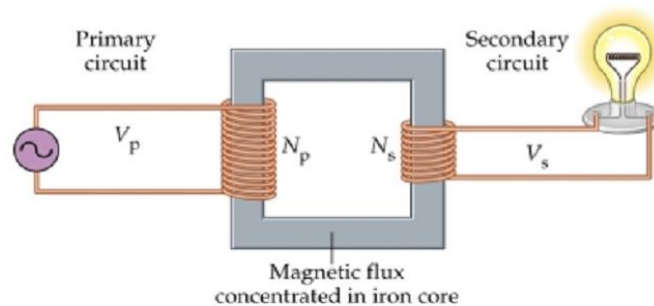
METHOD:

1. Put the solenoids next to each other and join them with an iron rod.
2. Connect the end of the outer solenoid to the terminals of the bulb / galvanometer.
3. Connect the inner solenoid to the 6 V power source, switch on and off, or rheostat to vary the resistor. (When the position of the switch on the primary circuit is changed from open to close or from closed to open, an EMF is induced in the secondary circuit).
5. Observe and record the following:
 - a) What happens to the bulb / galvanometer reading when you switch the current on as suggested in step 3?

- b) What happens while the current is flowing in the circuit?

- c) What happens when you switch the current off?

6. What type of transformer is this?



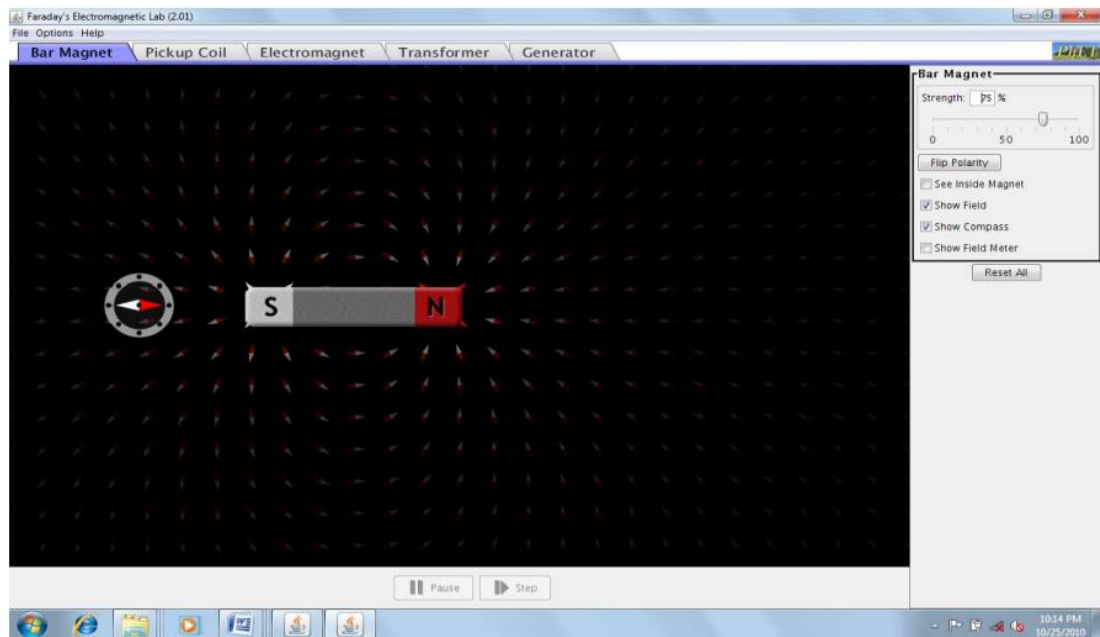
RESULTS/OBSERVATIONS

Record your observations (whether there is an indication of current induced, the type of transformer) in Step 4 - 5.

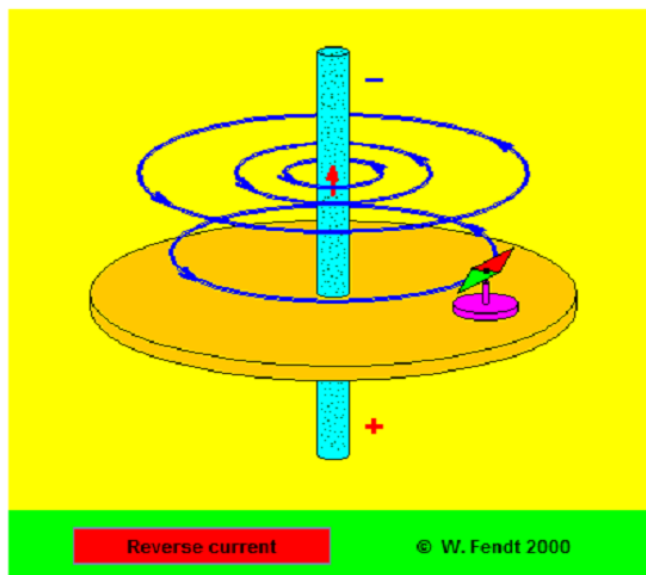
DISCUSSION AND CONCLUSION

Draw a conclusion from the above observations, stating and defining the name of the phenomenon observed in the primary and the phenomenon in the secondary coil.

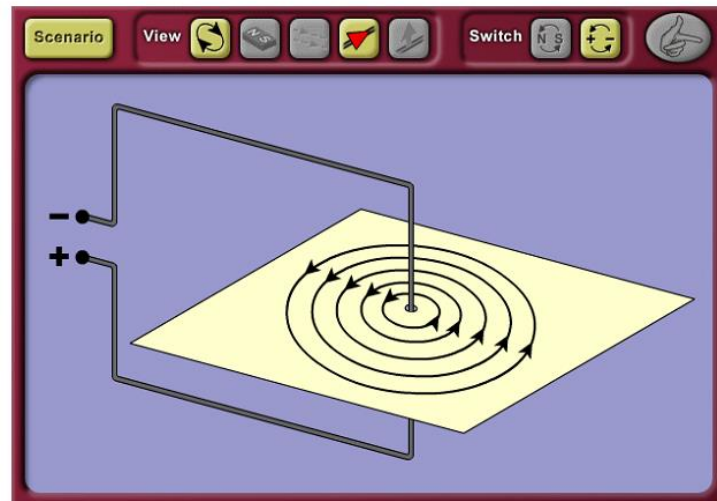
APPENDIX I: SIMULATIONS



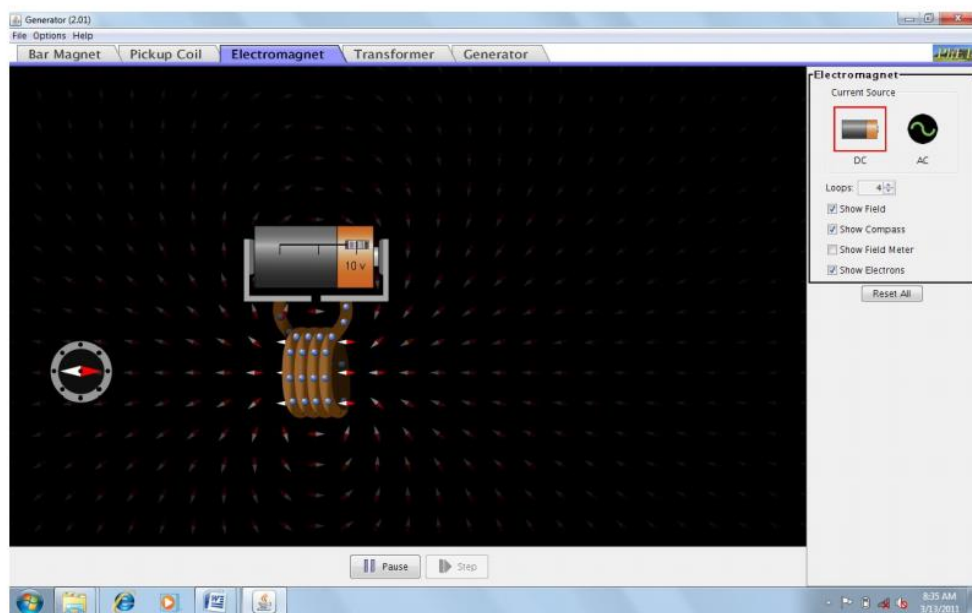
Simulation 1 (PhET)



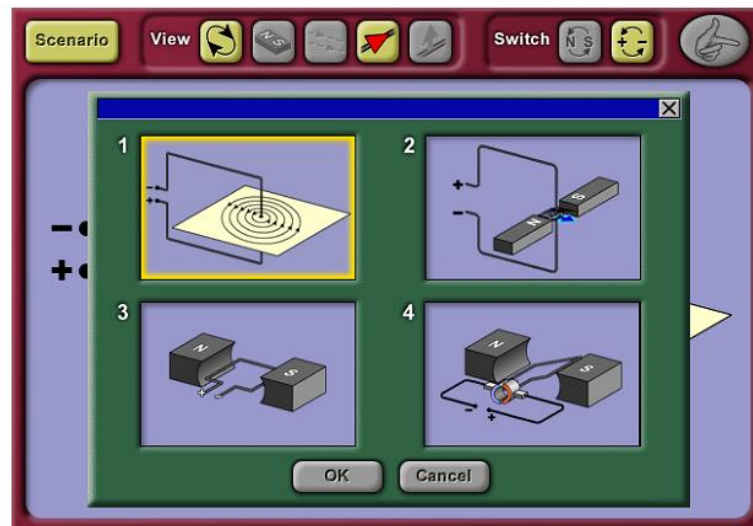
Simulation 2 (You-tube)



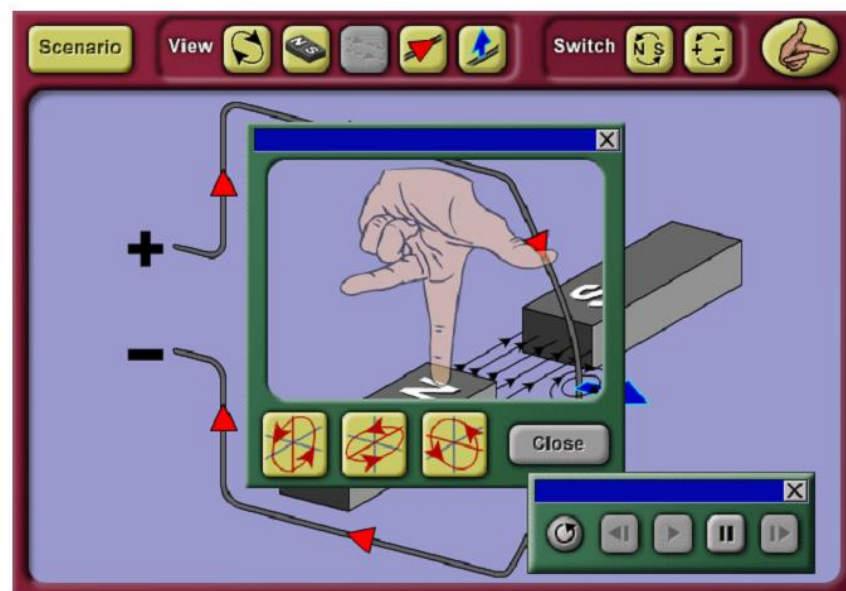
Simulation 3 (PhET)



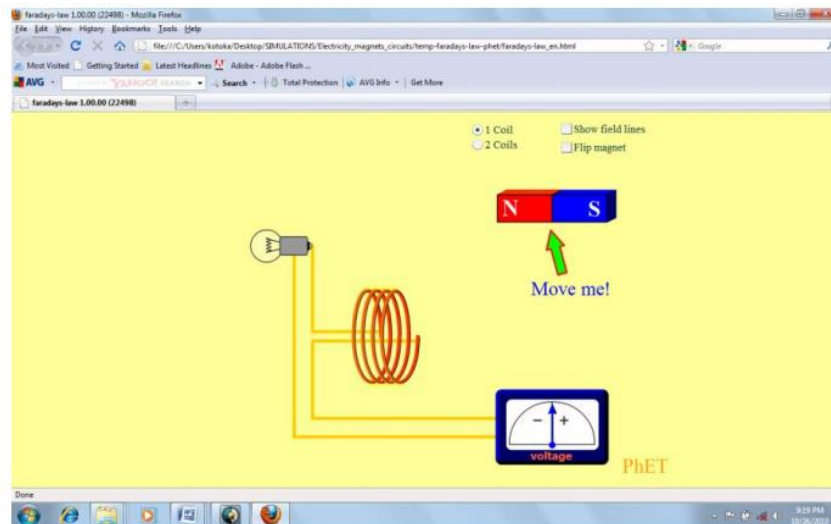
Simulation 4 (PhET)



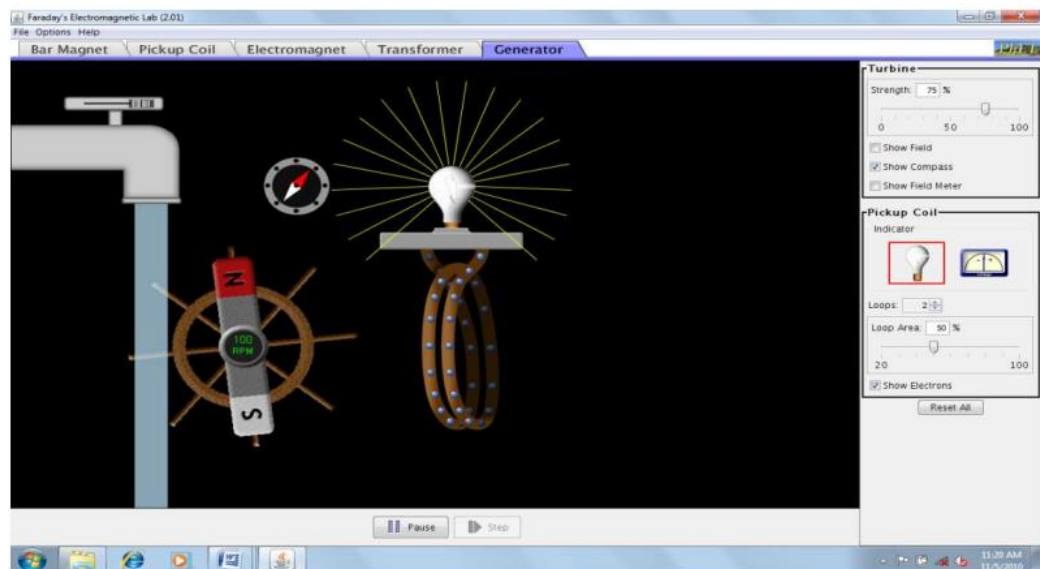
Simulation 5 (You-tube)



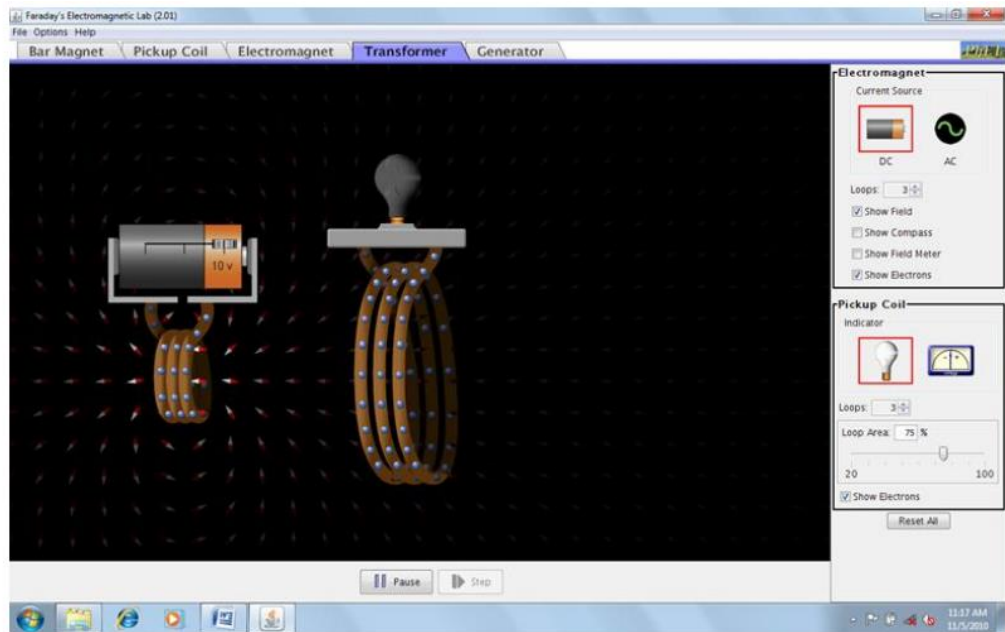
Simulation 6(You-tube)



Simulation 7 (You-tube)



Simulation 8 (PhET)



Simulation 9 (PhET)

APPENDIX J: VIDEO TRANSCRIPTS

1. CURRENT AND MAGNETIC FIELD

CURRENT

FACILITATOR: Stationary charges only have electric field. Force produced per charge hence, this is equation ($F = EQ$) that we talking about.

TEACHER: Mm...

FACILITATOR: I talked about electric field, electric field which is the force that is produced by a charge. Now I want to talk about the correspondence of the electric field and the magnetic field. How do they correspond? (*Demonstrating*), we have north and south they will attract; or will repel, if is north and north or south and south, am talking similar poles now.

TEACHER: Mm.

FACILITATOR: Watch this one? It's magnetic field (B), between two poles (*illustrating in a white board*). Now the charges, let's talk about the round ones, a positive charge and a negative charge (*illustrating in a white board*).

TEACHER: Mm

FACILITATOR: They are two different things but they have similar patterns, and look at the field is like almost the same (*illustrating in a white board*). There has been a confusion of magnetic field of a bar magnet, and electric field between two opposite round charges

TEACHER: Yah.

FACILITATOR: Ok let me name it, this is the positive charge, this is the negative charge, it will be like, this is from positive to negative, and looks like, north and south, it will be like magnetic poles. Look at the two, is like they are the same but this one is the electric field, this one is the magnetic field and this two will never interact. It's because this one is magnetic field and this one is electric field.

TEACHER: Yah.

FACILITATOR: Only magnetic fields interact with another magnetic field. Electric fields interact with another electric field, remember that. This charge has got its field now the two fields interact together (*showing in a white board*).

TEACHER: Alright

FACILITATOR: So it was two charges, there electric field, their electric field are interacting. But this field (electric) will not interact with this field (magnetic), it will not. You get my point?

TEACHER: Mm

FACILITATOR: Do you get my point? Electric field will not interact with the magnetic field. Only electric field will interact together and only the magnetic field will interact together. Is it clear? The unlike will attract and like will repel.

TEACHER: Mm

FACILITATOR: Ok when the charge moves it will produce a magnetic field. Now what interact its magnetic field of the moving charge or the current but not electric fields? We only have the magnetic field, only if we have the moving charge.

TEACHER: Yah.

FACILITATOR: Moving charge has got two fields; it has got electric field and magnetic field. A stationary charge is only having electric field, it doesn't have magnetic field.

TEACHER: So my point is, if I throw a charge in a magnetic field.

FACILITATOR: There will be interaction, though is not possible to throw a charge.

TEACHER: Ok

FACILITATOR: We're still talking the interaction of the magnetic field of the conductor or of the moving charge, and the magnetic field of the magnet. I'm

emphasizing the basic here, to understand the charge and field. Now I'm going to take the two drawings, look at the interaction, (*illustrating in a white board*) demonstrate the interaction. But what is important here, I'm sure that if we have a stationary charge we don't have a magnetic field therefore it will not interact with another magnetic field because it doesn't have a magnetic field.

TEACHER: And then I bring the magnet to that stationary charge?

FACILITATOR: There will be no interaction.

TEACHER: Is it not going to cause charge to move?

FACILITATOR: For as long as is stationary it will not move, but if it start (*illustrating in a white board*), 'this charge moving' then there will be interaction between the two because the magnetic field will be produced. I want to emphasize it, listen again; if we have a stationary charge we have electric field only.

TEACHER: Mm...

FACILITATOR: If we have a moving charge we'll have two fields, will have electric field and the magnetic field. Do you get that one?

TEACHER: Yah.

FACILITATOR: We have current flowing, but the conductor is, the conductor is stationary, but the charges are flowing. The charges are moving in a conductor, they are not stationary, the conductor is the one that is stationary, but now the charge are moving in that conductor. The charges are moving in the conductor they produce magnetic field. This magnetic field of the conductor is the one that interact with the magnetic field of the magnet, because only magnetic field interact with other magnetic field of the magnet.

TEACHER: Yah.

FACILITATOR: When you think you get confused, an electric field only interact with another electric field, very important; it will not interact with any other field. A

magnetic field only interact with other magnetic field, very important. 'Tebogo' are you going with me?

TEACHER (Tebogo): Mm

FACILITATOR: Right! Electric and magnetic field do not interact with each other very important and you need to mention that the learners; neh!

FACILITATOR: Ok good. Note. An electric current, the charge moving in the certain direction, we therefore observe the magnetic field around the current carrying conductor. The charge has got the three dimensional electric field around it, I'm sure you understand what I mean by 3 D. If the charge moves, they will be a field coming to you, they will a field pointing to me, there will a field pointing upwards, they will be a field pointing downwards, they will be a field pointing on the side, it is three dimensional. Do you get my point? Or if this pen is charge the magnetic field of this charged pen will be like this direction to this direction, to this direction (*demonstrating*), is three dimensions.

TEACHER: Mm

FACILITATOR: Especially for the learners, they can get confused, we draw it and we observe it in a two dimension, is two dimensional in a drawing. So they will only think that it only goes to north, south, east and west, they think about that way. It actually it's like a sphere producing magnetic field in all directions around that sphere. Yes that three dimensional, and our learners don't understand three dimensional. In Mathematics at tertiary we are talking about the X and the Y-axis and the Z one.

TEACHER: Mm

FACILITATOR: Its' three dimensional. A moving charge; now look at the second one here (pointing). A moving charge also has the magnetic field.

TEACHER: Mm

FACILITATOR: The blue lines represent the magnetic field. Now a moving charge also have the magnetic field perpendicular to it motion, so if it moves, it has an

electric field, and then the magnetic field will be created as it moves. Moving charges produce magnetic field perpendicular to the direction of the motion

TEACHER: Mm...

FACILITATOR: If this charge was moving this way there will be an electric field around the charge, a magnetic field symbolized by the letter B. Now if you look at this one the movement is this way, look at the field, here is like perpendicular (*illustrating in a white board*).

TEACHER: Mm

FACILITATOR: So they say is produced perpendicular to the direction of motion, if this is my conductor the charges are moving inside this conductor. If it moves, there will be magnetic field around, this magnetic field, if you look; it will take this way up, this way, this side (*demonstrating*), this is like circular motion.

So if the charges are moving this way, is perpendicular (90°) we showing...; this one is the current, is flowing like; or let me show with this two fingers because we normally use this one (*demonstrating* left hand rule), the middle one for the current, this one for the magnetic field. Right! (*illustrating in a white board*), If it moves this way, the magnetic field will be like this and this side, look at this side will be like this, down it will be like this, it will be perpendicular and end up, having a circular shape. So again I want to emphasize, moving charges produce magnetic field perpendicular to the direction for motion.

TEACHER: Mm

TEACHER: You are saying moving charges ...! Positive and negative charges produce magnetic field.

FACILITATOR: Mm

Ok! But normally in electricity we're talking a flow of positive charges in FET (conventional current). Right now we talking conventional current and conventional current is talking flow of positive charges. We're talking current and magnetism, and

when we talk current and magnetism when you talk current, you talking flow of charges, but then flow of positive charges because we emphasize that to learners.

TEACHER: Mm...

FACILITATOR: So when you say flow positive charges we assume we talking, positive charges. I know that little confusion; I can sense that little confusion.

TEACHER: Yah, because we know that positive charges like protons basically they don't move, they stationary.

FACILITATOR: Its' not moving, but relatively is looks like it's' moving

TEACHER: That positive charge is going there.

FACILITATOR: Yes, Do you understand?

TEACHER: Yah.

FACILITATOR: And when is start to move now it create what? "A new field", a magnetic field. 'Mr Dikole'?

TEACHER: This are thing that you have to explain to your learners, and if you get confuse, you need to clear confusions today. You need to ask questions, right. A magnetic field is produced by the motion of electric charge.

TEACHER: Mm

FACILITATOR: Very important. When the current flows in a single conductor or a coil a magnetic field is induce by the current. The pen is my conductor and the charges are flowing in this conductor. We know we only have flow of charges if we have a potential different.

TEACHER: Mm

FACILITATOR: If we have the voltage we'll have current flow the moment, and when I'm saying current am talking flow of charges, remember a conductor is the path for the charges. So the charges are moving in this conductor, as they move in this

conductor this charges inside the conductor, they've got electric field and the magnetic field as they move inside this conductor. So when current flows in a conductor or coil, magnetic field will be induced by the current. The magnetic field symbolized by B, we already mentioned that one.

TEACHER: Mm

FACILITATOR: An electromagnet is the name given to the interaction of magnetism and electricity.

TEACHER: Yah.

FACILITATOR: To emphasize that, we talking about the magnetic field develop by current, not magnetic field developed by magnet. Electric current and magnetic field, the sketches in the table below, the magnetic field pattern are formed in straight conductor a loop and a solenoid (slide 9). I want to emphasize here the magnetic field, no longer electric field.

TEACHER: Mm.

FACILITATOR: Here they are indicating what? The magnetic field. I'm not showing electric field now, remember the slide is showing both, but now it's starting to move, I'm leaving the electric field. Do you get what I'm saying?

TEACHER: Mm

FACILITATOR: So this is the magnetic field around the charge (*demonstrating*).

TEACHER: Yah.

FACILITATOR: Conversional current; now this is the conductor (*demonstrating*). Inside the conductor there are many charges that are flowing remember, and you must emphasize to the learners

TEACHER: Mm

FACILITATOR: When we connect a voltage to it all the charges will move at the same time, they will move at the same time. I normally do like this (*demonstrating*); this is my positive; this is negative, this is my battery; that is the voltage that I'm referring to. This is my conductor, for the learners, I will make it (conductor) a little bit thicker for them to understand, and I will say charges are like throughout this conductor. When you connect to the battery or to the power source all this charges that are here they will move at the same time.

TEACHER: Yah.

FACILITATOR: At the same time, when this one leave, the other one will be going into the power source to collect energy, and going out to go and use the energy somewhere.

FACILITATOR: Now that one charge, if it moves it will have a magnetic field. If we have many of these charges, you will have many in the conductor producing magnetic field.

TEACHER: Mm

FACILITATOR: So when you look at the conductor, conductor is stationary, but if voltage is in the conductor what happen? Charges are moving that what we emphasize to learners that the conductor is like path for the charges.

TEACHER: Mm

FACILITATOR: Is just a part, so the charges will be moving. If current is going up...! What is current? Flow of charges, flow means there should be something moving. Charges are moving, so it is the current, meaning is the flow of the charges, so we'll be having lot of magnetic field and this lot of the magnetic field, so many magnetic fields will form around the conductor.

We'll do the experiment, you will do it, you will see we got the magnetic field around conductor because all the charges that are flowing are producing a magnetic field but remember is inside the conductor. So if is a loop, you know is nice to demonstrate. Now I don't know what happen with my loop (*looking for a loop*), but

we can make our own loop. (*Demonstrating*), this looks like a single conductor. This is a single conductor; when I connect a battery, the charge will start to move in this conductor, and the charges, as they move they will create a magnetic field in such a way that it will be like perpendicular to the direction of motion. So if the charges are moving upwards, the magnetic field will be like concentric around this conductor. So if it is concentric (*demonstrating*), meaning this side will be facing to you, this side will be facing there, this side there, this side will be facing there making a concentric shape. So if it is pointing to you, this side it means; the current is like 'this'; in my conductor. Is like this way and this is my field, is perpendicular (90°). If it is pointing this way, like that, it will be 90° .

Actually for the learner to understand we use what we called right hand screw rule to indicate. For the rule we say: (*demonstrating*) this is your right hand they will tell you to hold the conductor with your right hand.

TEACHER: Mm

FACILITATOR: And then we saying the thumb represent the direction of the current, the thumb represents the direction of the magnetic field. So we say! It's like concentric. The magnetic field is concentric around the current carrying conductor, when the current flows through the conductor we say it's current carrying conductor, when it flows in the solenoid we say, "current carrying solenoid", it's just a language we use in science. So to indicate the direction, what do you check, (*demonstration*) these are your hands, they go like 'is it clockwise or anti-clockwise'?

This is my conductor it's going like (*demonstration*) 'this', so this side will be pointing up/ down and this side will be pointing up. So it's a concentric circle, and also to emphasize to the Teachers the arrows cannot coincide. It should be like it's 'going there, it's going there' you shouldn't have a situation where this side the arrows are going this way and this side this way, because the magnetic field has got direction, it always goes from positive to negative. So it always has direction.

(*demonstration*) So this one is going where? 'Out of the page' how do we know? 'The dots' because they are pointing out, 'use the pen' what are we saying? If you see the dots, it means the direction is going out of the page. So its field is circular,

we have to test to see (observe) the experiment today. So it will be like...! What is the direction? What is this direction? Is it clockwise or anti-clockwise?

TEACHER: Clockwise

FACILITATOR: When current gets into the page, so this one is going out of the page meaning your thumb must point out of the page, because is the one that represent the current. Right! Curled finger represent what?

TEACHER: The magnetic field.

FACILITATOR FACILITATOR: This is the definition of right hand rule. If they say define or state the right hand rule; (*demonstration*) you will say hold the conductor, with the thumb that is pointing in the direction of the current and the curled finger pointing in the direction of the magnetic field. So it is the actual explanation. So you hold a conductor with your right hand with the thumb pointing in the direction of the current out of the page.

The magnetic field will be like circular, (*demonstration*) so 'this' side will be like up, and 'this' side will be like down. So it will be like the arrows must point in one direction, clockwise or anti-clockwise. So 'this' one is what? 'Anticlockwise'. So this is one of the questions they ask, is this grade 10 and 11?

TEACHER: Yes (*syllabus*)

FACILITATOR FACILITATOR: Is it clockwise or anticlockwise? Don't forget the directions they use in the right hand rule, and then they will know (*Teachers*). So it was going up and once it goes up it creates many magnetic field, many of these (*demonstration*) , lets imagine it was here and the other here in the same phase, so we will have a magnetic field around this whole conductor, so it's not because of the conductor it because of many moving charges in this conductor.

So even the loop, the loop is still a conductor it's just that you have either..., you can have a rectangular loop and / or circular loop. (*Demonstration*) This is like a loop but this is also a loop. Actually you will see and most of the time we will indicate the loop like this, but when you get to grade 12 where we talk about the coil in the magnetic

field. Those motors and generators will tell you about the rectangular loop. So what is important; this is a loop, it's still a conductor I'm emphasizing that it's still a conductor so in this case we have a single conductor, a loop and a solenoid.

All of them they are conductors, that's why I was saying, the most used (*emphasized*) is a single conductor (*in FET phase*). So this one it's a loop, whether it's round or rectangular this is a loop. Now if this is a loop, if we can connect current, the positive terminal and negative terminal. You should actually relate this to your grade 12, this is the basics I'm talking about, but you'll also find it in grade 12. This is my loop, if this is my conductor, this conductor throughout has got a magnetic field; we are not talking about the electric field outside the conductor. Outside the conductor we'll be having a magnetic field; the magnetic field will be circular, meaning this side will be like circular.

So if we have two magnetic fields they will interact, (*demonstration*) so we will have a circular movement here and a circular movement here. When the two magnetic field interact we will have a bigger magnetic field, this side a smaller magnetic field, they combine to cancel or add at that time, if this is a positive terminal, the 'black part' this side it's a negative terminal, so the current will be from positive to negative. So if I put it like 'this' from the positive to the negative, 'meaning this one will be going, 'into the page or out of the page?'

TEACHER: Into the page

FACILITATOR FACILITATOR: Going into 'going, going, going' (*demonstration*) and this side is pointing out of the page. So this is actually...! I think a representation of a loop whether it rectangular or circular, so the magnetic field here going 'into' is pointing down, this is going out. There's a magnetic field this side, and the other side. The two will interact, 'why?' because they are both magnetic fields. That point that I was emphasizing, 'only magnetic field interact with magnetic field'.

Now this one remember (*demonstration*), it becomes stronger and as it goes away it becomes weaker, so here it was going like 'clockwise' and this one was going like 'anti-clockwise', 'look at this side, it goes in the same direction'. So it means when they go in the same direction they combine. Let me make an example, if this one

'turns' and this one 'turns', they can combine we'll have a resultant of the two magnetic field.

(*demonstration*) if we have a force of 20 going this way and we have a force of 10 going this way, whether in Newton's or tesla for the field, this one is the force of the magnet. If they go on the opposite directions what will be the results 'here'? The results will be 10 'this way'. Now the force, what is the force? The force is a push and /or a pull, so the combination of the two will produce a 10 which is the net force. The net force will be 10 and because the force is the push/pull, this 10 will push/pull the conductor. That force it was the interaction of the two forces, we have like 10 this side and 20 (opposite direction) this side, so it will push. Why does the conductor move? Right now I just wanted to show you the forces around the loop, so this is the situation, this is my conductor, (*demonstration*) and 'this if from....., and this is from.....' so the current is flowing this way, you see? So if it goes here his is like pointing up and the magnetic field will be like this 'you'll see in the drawings there' this side is pointing 'this way' and also this side is showing the same thing that I was showing here.

So here will have magnetic field very strong, now if we have a solenoid or a coil, what is a solenoid/coil? It's like many of the coils, this time we don't have one coil. The moment we have the next turn, we call them turns', the number of turns. We can wind it so many times until we have a solenoid. So we have a representation of 'this'(*demonstration*) many times. I just want to show you, if it's one; it's single and if it's two they combine. If it's a coil it's like 'this' and if it's many of 'this' it's a solenoid, they combine.

(*demonstration*) If this is my solenoid current will be flowing like 'shows with a thumb ' so look at this one it will be like going into the page and going out of the page, 'it's a loop' (*demonstration*). Then it will be like going into the page, getting out of the page. This is a representation of a solenoid. We've got the conductor while it has got the magnetic field, magnetic fields around the conductor are all the same, they are all round and they indicate the directions. So let's look at this one, going into the page, is it clockwise or anti clockwise?

TEACHER: Clockwise

FACILITATOR FACILITATOR: Same thing; going into the page 'clockwise' and going out of the page?

TEACHER: Anti clockwise

FACILITATOR FACILITATOR: You must be careful, I'm pointing..., (*demonstration*) my finger is pointing outside. So the thumb must point out of the page. Now because all these conductors have got a magnetic field and the magnetic field will interact with another magnetic field, this magnetic field will interact. So at the end we'll have an interaction 'there' in the middle (*pointing the drawing*) which is very strong, and the interaction outside being very weak.

(*Demonstration*) Look at this one between the two conductors, this one is pointing down, and in between these ones are going in, and this one is going up, which means they will cancel out. Because the other one is going up, and the other one is going down. If it's 10Tesla up and 10Tesla down for example, it will be zero resultant. So in the middle we will have a very strong magnetic field (20Tesla), current consisting of charges moving in the same direction. Magnetic fields of all the individual charges form the observed magnetic field around; we've been explaining it so many times, 'the wire, a circular magnetic field or (concentric circle)'.

To work out the direction of the magnetic field in the conductor, you use the right hand rule and I've explained it. Curl the finger of your right hand and point the thumb straight, with your thumb pointing in the direction of the current flow and your curled fingers will be pointing in the direction of the magnetic field. On the flat surface, like this table, two currents move in the opposite directions in the loop. In the loop they'll flow in the opposite direction as I've shown you.

(*Explaining*) The magnetic fields of the two current combined, I'm going to emphasize that. A solenoid consists of a number of current loops and the magnetic field of all the current loops combined, and the magnetic field of all the current loops will combine to form a combined (net) magnetic field. A magnetic field around a current solenoid makes a pattern of magnetic field around the magnet 'you've seen that one' It's that one that I was emphasizing there. A ferromagnetic material in a conductor is a material which becomes magnetic when there is current flow around

it, I'm bringing the electromagnet now because the theory that we were talking about now brings in the electromagnet, and for you to understand the electromagnet, you must know how current behaves in a solenoid. If you understand how current behaves in a solenoid, we say it creates a strong magnetic field, according to my drawing (screw rule), it will still be strong, were? In the middle. So if you want to make a magnet, bring a magnetic material, the 'ferromagnetic'. This pen is not a magnetic material; let me show you an example of an electromagnetic material' (*showing*) 'an iron'. You see this magnet? If we can remove this paint you'll see a magnet material. Now if you can take a ferromagnetic material, 'can someone borrow me a coin?' (*Testing if is a ferromagnetic material*).

(*Demonstration*) If you can take a ferromagnetic material and put it inside like this (*demonstration*), this magnetic field that is created by the coil will magnetize the material in such a way that it will behave like a magnet, so it will align this magnetic domains in such a way that it is very strong magnet, they will align like this (*demonstration*). It will have the North Pole and the South Pole, the patterns that are inside will be aligned, so this will become a magnet and that is how we make a magnet, and this magnet we call it an electromagnet because it is the magnet that is made from electricity. Ferromagnetic material is a material which becomes magnetic when there is current flowing around it.

Not all substances can be magnetized easily nor do all substances lose their magnetism easily. We have magnetic material and non-magnetic material. The magnetic material, there are those that can be magnetized easily and there are those that can't be magnetized easily. Substances like iron are easily magnetized and de-magnetized. I can magnetize it now and you will get a magnetic material, but after switching off the current it loses its magnetism. So it's easy to be magnetized and easy to be de-magnetized, and those are soft magnetic material.

TEACHER TEACHER: How possible is that? (*Seeking clarity*)

FACILITATOR FACILITATOR: It will still have two poles because the magnet has got a north pole and a south pole, whether it's a strong magnet or a weak magnet it will have a north pole and a south pole. Even if you break it into two, you'll still have a north pole and a south pole. When it loses its magnetism, it means it

loses its direction of the alignment; the alignment gives a south and a north pole. If it loses its alignment, we'll not get a magnet anymore. A magnet can lose its magnetism after a while simply because it was made by a soft ferromagnetic material.

All the magnets like steel are difficult to magnetize, that's why it's difficult to take a still and make an electromagnet. Unlike this 'one', (*demonstration*) this one you will see it will be magnetized, it wasn't attracting the coin but it's now attracting because it's easily magnetized. But the ones that are difficult like steel, they use high current but they last longer and are hard magnetic material.

Magnets are used for different things. We've got magnets that we use to take out heavy stuff (lifting magnets), it's a very strong magnet. So it was made from a hard magnetic material; like iron as an example. Strength on the magnet depends on the current in the conductor, the more the current, the more the magnetic field. Number of turns, if it's one loop the magnetic field is weak, if there are more loops combined there's more magnetic field. Types of the substance; is it the soft ferromagnetic material or hard one? Electromagnet comes in variety of sizes, we've got different sizes, shapes and strength, and strength you see that one that they use in the scrap yard which is very strong. It is used in variety of appliances i.e. loudspeakers, telephones receivers, etc.; so this is very important to life.

FACILITATOR: Test yourself, 'let's go now'; I can see some are getting sleepy. Let's discuss: In order to achieve unlike magnetic poles at the end of the magnet; I know you have a horse shoe magnet at you schools, but you've seen it before right?

TEACHER: Yah I've seen it before but when you

FACILITATOR

FACILITATOR FACILITATOR: Ok, we start testing ourselves; I want to check if you've been listening. If all magnetic poles are like this (*horse shoe shape*); in order to achieve unlike poles at the end, the limbs of the magnet must both carry current in which direction (refer to slide 17).

TEACHER: C (*answer*)

FACILITATOR: The answer is C? (*Checking the answer*)

FACILITATOR: Ok, before that maybe I need to mention this also, I forgot ok! Remember I said the magnetic field around a single current carrying conductor, we use the right hand. The current carrying solenoid we also use the right hand ok (screw rule)!

TEACHER: Mm...

FACILITATOR: Pick up the difference, ok! For the solenoid we also use the right hand rule, but for the solenoid the fingers will represent the solenoid, not the magnetic field like current carrying conductor.

TEACHER: Mm...

FACILITATOR: Let's talk about a single conductor, let's start with a single conductor ok! In a single conductor (*demonstration*), this will be the direction of the current; this will be the direction of the magnetic field. For the solenoid this will be the direction of the current, this will be the direction of the magnetic field. For the solenoid this will be the direction the current, this will be the direction of magnetic field

TEACHER: The vice versa?

FACILITATOR: Vice versa yes, right. So if this is our solenoid look at this one (*demonstration*), this is the situation; here you are going like, 'in page and go out there ok! So this is the direction, this is the solenoid here ok!

TEACHER: Mm...

FACILITATOR: So this would be my north, this will be my south. It will actually be indicated by the arrow. You don't have to draw all the magnetic field around each loop of the solenoid ok! You just have to use the right hand solenoid rule. So you know that if, like! If the loop goes, like! 'Clockwise' or 'anti-clockwise'. That is what they ask also in motor and the generator (*grade 12 examination*). They usually ask! 'Clockwise or anti-clockwise' (*Connecting to grade 12 question*). Grade 12 this thing of clockwise direction, anti-clockwise direction, they like asking it

FACILITATOR: (*Further demonstrations and discussion*). Now this, look at this one, is this clockwise or anti-clockwise? It is going into the board, going behind the board, going out of the board, like, it winded like the solenoid ok!

TEACHER: Mm...

FACILITATOR: Is getting into the board, behind the board and going outside the board, and going again in the board (rotation)!

TEACHER: So you only see it when you do this, to follow the pattern, but then you'll have to push your hand up (*demonstration*) to check whether is clockwise or anti-clockwise.

FACILITATOR: Come again (*Seeking clarity*).

TEACHER: You follow the direction of the current like (*demonstration*)

FACILITATOR: The direction of the current is very important.

TEACHER: And then I will take the tip of my pen to note...! (*Demonstration*) so we'll put the pen like this, but then when my hand is like this I can't tell whether is clockwise or anti-clock wise, I have to make it...

FACILITATOR: Is like that pen is a ferromagnetic material.

TEACHER: Exactly...

FACILITATOR: Is a ferromagnetic material so the fingers are like they are rapping around the ferromagnetic material ok! But the most important thing like you said, is not actually the rapping, is about the current is flowing clockwise from the power source. (*Demonstration*) this end to this end so is going like...or is going like ...like that right. But if you look at this you can just say the sides are going into and out of.

TEACHER: Mm...

FACILITATOR: So is like this (*demonstration*). So is like, this is my north pole; this one is my south pole, without having to write a circle and the arrows (*emphasizing*). Can I pass this point?

TEACHER: What is the answer?

FACILITATOR: This is the solenoid rule (*demonstration*). So if this is pointing...; this will be like into..., do you see, and this one it will be like this, ok! It means this side it will be pointing! So this can be the south, this can be a north. So now this current, so this one is going like this way, this one is going like that way, so the answer is C.

TEACHER: Yah.

FACILITATOR: When magnetic fields of different sources are in the vicinity of each other they interact with one another. The interaction causes motion; we only focus on the interaction between the magnetic field of the permanent magnet or bar magnet, and the magnetic field of the moving charge. So when the magnetic fields interact they will cause motion, why do they cause motion? Because there will be a resulting force, and once we get a resulting force we get acceleration that is directly proportional to the force and inversely proportional to the mass of a conductor, according to the Newton's second law of motion.

FACILITATOR: Alright, can we just pause here and then when we come back I want us to do experiment on everything that we were talking about before we continue to the interaction now ok!

TEACHER: Mm...

FACILITATOR: We can go for lunch

2. MAGNETIC FIELDS INTERACTION

FORCE EXPERIENCED BY UNIT POSITIVE CHARGE

FACILITATOR: 'Electric force it's very strong. ...!

TEACHER: Mm...

FACILITATOR: (demonstration) so because a force is a push of a pull! It will pull; remember this is my conductor! The force is strong above, it is weak this way, this force will now push 'this', and it will push 'it' down. So you see this interaction will produce movement or motion, it will produce motion. Do you get?

TEACHER: And then how we explain that in parallel doesn't experience a force...

FACILITATOR: Doesn't experience, can we try to work it out together!

TEACHER: Yah.

FACILITATOR: Let's say the current is going inside, no is going that way. So if it goes that way as the magnetic field there. 'This' is my current, if is like this, is going this way! So this is the magnetic field, but I am sure you can imagine.

'This' one is a magnetic field is not the conductor

TEACHER: So just show where is going

FACILITATOR: Mm... We're showing it like a conductor but you must be careful because it can confuse others. (*Same demonstration as current carrying conductor*)

TEACHER: Yah.

FACILITATOR: The magnetic field from north to south, you see. Remember the motion of the charge must be perpendicular to the magnetic field! So if is parallel, I'm trying to check the combination of the magnetic field; what is going to happen? It tells me the magnetic field will be like 'this' (*resultant of the two perpendicular forces*).

TEACHER: Yah. That's the magnetic field.

FACILITATOR: Magnetic field of the conductor will be like 'this', then the magnetic field of the bar magnet, north to south. This one is the field, not the conductor; I don't want to confuse others. With this I'm trying to represent the direction of the magnetic field around the conductor it will be like this, now it is like this; this means the resultant of the two will go this way.

TEACHER: But it looks like they don't mix

FACILITATOR: I'm saying, what I'm saying is that we'll be having two magnetic fields! The other magnetic field is this way and the other magnetic field is this way. These ... like forces when the other forces are this way and the other forces are this way, what is the resultants force? This way, that why I'm saying it will be like perpendicular, it will be like this way. The magnetic field of the magnet and the magnetic field of the conductor and the resultant will be like this way.

Listen again, I don't want to end up confusing people but now if we look at other the magnetic field of the bar magnet is in the same direction throughout.

TEACHER: Yah.

FACILITATOR: It is the direction of the magnetic field around the conductor? Because it goes clockwise, (*demonstrating*) so the other side it goes like that (inside), and the other it goes like side! So when it goes outside it will be like magnetic field, this one is going outside! So it end up like cancelling each other it will make like angles cancelling each other, the other one will be going ... resulted as, the other one resulted this way, so they end up cancelling each other, there's no point where they can join each other or where they cancel each other totally.

I want to be careful not to bring more confusion because now we have to talk about the magnetic field going into the page and going out of the page. We usually talk about the current going into the page and current going out of the page and that is magnetic field. But the most important point that you should know and remember is that, when the charge is moving parallel to the magnetic field there will be no force.

And maybe one more thing to say if its moves perpendicular to the magnetic field, there will be more force. If the angle decrease the angle between the flux which is represented by Φ ! A moving charge, we say is moving with the velocity (*The motion of the current or velocity*). If the velocity of the current is into the page; that is if the conductor is going in the page, meaning the charges are into the page. The terminology that we use in Physical Science we say the charge has got the velocity.

TEACHER: Yah.

FACILITATOR: The magnetic field is represented by B, right. So we are talking about two things, velocity of the charge and the magnetic field .What will happen? We'll have a force. Force on what? Force on this charge!

TEACHER: Mm...

FACILITATOR: Hence to calculate that force, we say that force is $F = QVB$ because looking at the interaction... I want to emphasize that we're talking the interaction between the direction of motion of the charge and the field, not the direction of the field of the conductor and the field of the magnet. Do you get my point?

TEACHER: Mm...

FACILITATOR: You know it can be very confusing to learners if you don't emphasize what I'm emphasizing right now. We're looking at two things the magnetic field and we looking at the motion of the chargers. Now point number one if that charge is stationary in a magnetic field there will be no force! If that force is moving, we say there will be force! But if it moves parallel to the magnetic field, it will not experience a force!

TEACHER: Mm...

FACILITATOR: And but if it moves, listen to this one, if it moves perpendicular to the magnetic field, it will experience a maximum force. So if it moves between parallel and vertical, it will also experience a force, but that force will be less than when it is perpendicular!

TEACHER: Mm...

FACILITATOR: I'm talking about the charge right now and in a coil we'll be talking about many charges flowing in the coil. Now those charges, because they are many, the force experienced by each and every charge, they combine and form a very big force that will actually pull the conductor. So the conductor is pulled by what? By the interaction of the moving charge field and the bar magnetic field, hence we say electromagnetism.

FACILITATOR: That is the most important thing, and a basic application of motors

TEACHER: Yah. (Trying to seek clarity of motors and split rings (grade 12 syllabus)

FACILITATOR: (Illustrating how split rings produce direct current). At the time where we have contact that is the time when the other half is on one side, when this other half goes to the other side, that is the time where there is no contact.

TEACHER: Mm...

FACILITATOR: But the most important thing is that there must be contact; no contact, contact; no contact, which is the most important thing, you must emphasize, “alternately”.

LOAD SHEDDING

FACILITATOR: You know that because of the problem of the electricity I’m going to switch off my laptop and then what we going to do, you have presentation in **hard copies**. I’m also going to use and tick to my hard copy, then when we need to demonstrate I will switch my laptop on to show a simulation because the battery will need charging and the lap top will turn off.

FACILITATOR: Explain how to proceed because of load shedding. Start on page 06 of the hard copy of the presentation. “Electric current and the magnetic field” (sub topics) that is where we ended yesterday.

3. INDUCTION

FACILITATOR: Electric current and magnetic field

There is link between electric current and magnetic field. Yesterday we talked about current and then end up having movement right (current producing magnetic field). Now today we don’t have current at all. What are we doing? We are producing current, we are inducing current right. Producing magnetic field from electricity, we may produce electricity from a magnetic field. There is one important difference...., there is one different between the two.

TEACHER: Mm...

FACILITATOR: Electromagnetism produces steady magnetic fields from a steady electric current remember! a steady DC current produces a steady magnetic field right. Electromagnetic induction requires motion between the magnetic field and the coil to produce voltage now that is knowledge that you should always remember because everything is going to build on that. Electromagnetic induction required motion between the magnetic and the coil to produce voltage right. There must be motion between the magnet and the coil right. It doesn't matter whether the coil move or whether the magnetic field changes. If the magnetic field is moving relative to the coil then electric current it is induce in the coil, the process is called electromagnetic induction.

TEACHER: Explain again!

FACILITATOR: If you move the magnet towards the coil, the current is induced and the process is called electromagnetic induction. For one to induce the current, we need the magnet and the coil, and movement is the most important thing. There must be movement relative to each other (**slide 33-34**).

TEACHER: Mm...

FACILITATOR: They must not be stationary, if they are stationary then we'll not have current being induced in the solenoid. So either the coil is stationary, and move the magnet into the coil like this into the coil right (*demonstrating*).

TEACHER: Mm.

FACILITATOR: What am I doing here? (*Demonstrating*) This is my solenoid right, so if this is my solenoid this is my magnet, if push the magnet into this solenoid or if I push it out current will be induced. If I leave magnet inside, and not moving, there will not be current induced.

TEACHER: So in that case "mam", our charges are stationary.

FACILITATOR: Charges are stationary.

TEACHER: Then change in magnetic field cause our charges to move?

FACILITATOR: To move, therefore we have current induced.

TEACHER: Mm...

FACILITATOR: So we have to move or you can keep the magnet stationary and push this in the magnet, push it out from the magnet, either of the two. So the most important thing is movement, the magnetic field cuts across the conductor.

TEACHER: So anyway are we're saying the magnetic field of the charge is going to be induced, the magnetic field around the stationary charges, and then interaction between magnetic fields is going to produce.

FACILITATOR: The magnetic field, as is pushed inside it will induce current, it will make the charges to move and as the charges moves they will create their own magnetic field. Remember when current flows, remember yesterday we said when current flow in a conductor it will create magnetic field (*trying to link today's explanations with yesterdays*).

TEACHER: Ok.

FACILITATOR: Yesterday we said if we have current in a conductor we will have magnetic field induced.

TEACHER: Exactly.

FACILITATOR: Right. Now we take the magnet, we don't have any power source, you don't have any voltage, and we're not giving any current. I just push my magnet into this (solenoid),so the magnetic field crosses this whole area (*demonstrating*).

TEACHER: Mm.

FACILITATOR: It makes the charges in the conductor to start moving

TEACHER: Mm.

FACILITATOR: Now if they move what does it mean? It means we have electricity now, now you leave this one (*demonstrating*), I push, after pushing what happen there? The current flows.

TEACHER: Mm.

FACILITATOR: There's movement. And when the current flows what happen? It produces the magnetic field.

TEACHER: What causes the current to flow?

FACILITATOR: The change in magnetic flux is what makes the current to flow.

TEACHER: I still remember you said. . . . Magnet is; then the ability to produce magnetic as well as the...

FACILITATOR: Yesterday I said, if the charge is moving it will produce magnetic field. It has; remember we said it has own electric field, and when moving it will have electric field and the magnetic field. So you only have magnetic field when? When there's movement of charges. So when I push my magnet in to the conductor, that change in magnetic flux cause by 'this' (*demonstrating*), will produce current in the conductor to flow. So when the current start flowing is because of the change in magnetic flux. I want you to get this one; the current is flowing in a conductor because of the change in the magnetic flux. So we have a change in magnetic flux and what happen? Voltage it is induced, when the voltage it is induced it means there's is current flowing.

Now when current flow into this! We'll have the magnetic flux of this one now. When the current it is induced in the solenoid, it will also produce its own magnetic field? So is like we have magnetic field number one, lets' label them, magnetic field number one ; the magnet is pushing in to this(*demonstrating*), the magnetic field number two is induce by the current in the circuit, you get what am saying?

TEACHER: Mm.

FACILITATOR: Now the current that is flowing in the solenoid it produces its own magnetic field, lets' call it magnetic field number two. Where does the magnetic field number two come from?

TEACHER: From the moving charges. . .

FACILITATOR: From the moving charges (induced emf). Where does the moving charges come from?

TEACHER: From the ma...gnet

FACILITATOR: The change in magnetic flux.

TEACHER: The change in magnetic flux of the magnet; cause the charges to create its own magnetic field that is opposing the change in magnetic fields of the magnet. Once the second magnetic fields are produced, they cause the magnetic field that will oppose the one of the magnet.

FACILITATOR: Now this emphasis is what we were talking about yesterday. The magnetic field is only induced when the current is flowing. So for you to have the magnetic field what you need, you need movement, (*demonstrating*), so what is this thing doing? It is causing the charges, so as they move, the movement of this moving charges cause or produce own magnetic field. I want us to understand how movement of the charges, or what causes the movement of charges and what cause the induce emf again.

TEACHER: Yah.

FACILITATOR: That is the basic that you should actually keep in mind. For the charges to move we need a change in magnetic flux and what we mean by the change in magnetic flux. (*Demonstrating*) Remember this is our magnet right, whether is north or south it doesn't matter right. It will go like this

TEACHER: Mm...!

FACILITATOR: So here is very very strong right (*using a drawing to demonstrate*). Now let me push my solenoid, I don't know how will I push my solenoid but as we ...,

let say we have your solenoid right. When you push this look at the magnetic flux here is very weak?

TEACHER: Mm...

FACILITATOR: (*using a drawing to demonstrate*) as you push the magnetic field is becoming strong, as you push it becoming strong so what happens? The magnetic flux changes across, that cut across the conductor; it changes, is not steady. Then when you have a change in magnetic flux, it will cause the charge in this conductor to move. So what cause the movement of the charges? The change in the magnetic flux. Now when the change, we have current, and when we have current now, what will happen? We should an induced magnetic field.

TEACHER: Yah. .

FACILITATOR: The magnetic field on the bar magnet is the one that induces the current in the conductor, only when it moves, only when it changes. Then if the charges start to move it will create its own magnetic field, and we saying that field will oppose

TEACHER: Mm...

FACILITATOR: What I am explaining to you is actually faradays law

TEACHER: Yah.

FACILITATOR: Is Faradays. There must be a change in magnetic flux for the current to be induced in the circuit.

TEACHER: Mm...

FACILITATOR: There must be a change in magnetic flux for the current to be induced in the circuit. For now lets' not talk about the magnetic field caused by the current; for us to have a current flowing, the induce emf..., we need change in flux!

TEACHER: Mm....

FACILITATOR: We need what? The change in the magnetic flux, and it just not theory, you do it practically you will see. It's something that is interesting.

TEACHER: That what I wanted to see

FACILITATOR: I will show it to you now; I need to have a simulation that is showing that. I will show it to you but I want you to understand it so when you observe it, you now understand what is it? What you mean by induction? What you mean by electromagnetic induction, we are inducing the emf by doing what? By changing the magnetic flux, to cut across the conductor or the solenoid.

TEACHER: So what happens to the magnet field created by the moving charge, move these things quickly?

FACILITATOR: It also creates its own magnetic flux right, so they don't interact they don't want interact. . .

TEACHER: That is what I want to ask?

FACILITATOR: Now the current in that conductor are produce its own magnetic flux and we say the magnetic flux is in such a way that it opposes the original magnetic flux. Now what am I saying? Lenz law now comes in; Lenz law now comes with the direction. Faradays comes with the induce current, the induce emf that to induce the emf we need a change in magnetic flux, how do we acquire magnetic flux?

TEACHER: Mm?

FACILITATOR: Lenz emphasize the issue of direction.

FACILITATOR: What am emphasize is that charges are push, a potential different is induced, we call it the induced EMF.

TEACHER: Mm...

FACILITATOR: So when the current start to flow, I want you to separate the two, faradays law and Lenz law. Lenz law is actually adding on faradays law maybe that's why you confusing them. First the change in magnetic flux will induce voltage its

faraday. Lenz comes and said, this current that is flowing, what is the direction of that current? Lenz wants to check, what is the direction of this current, and realized that the same current that is flowing produces magnetic field that is opposing the original one (magnetic field of the bar magnet).

TEACHER: Yah.

FACILITATOR: And now it takes us to the right hand solenoid. Ok, let's see if I was pushing is in North Pole, if I was pushing to the North Pole the current flows, so what is the direction of the current that is flowing? It is clockwise or anti-clockwise? But then we realize that, when we push it inside it create current and that current is producing own magnetic field in such a way that, the front of the coil, If I push North Pole it will have its north pole also at the front, opposing. You understand?

TEACHER: Yah.

FACILITATOR: So he was saying then he has to use the solenoid rule to check the direction of the current. If he changes and push in the South Pole, he realized also again that the front part, when pushing the South Pole it create its own magnetic field in such a way that this become the South Pole. So he was able to get the direction of the current flowing in the conductor. Do you get what I'm saying?

TEACHER : Mm...

FACILITATOR: But you see Lenz law was working on faradays work. Faradays is the one who realized when you have the changes in magnetic flux, voltage will be induced, and then Lenz law further make a further research and find out that current that is induced is producing the magnetic flux that is opposing the original flux. Do you understand what I'm saying?

If you look at the equation for faradays is the same as the equation for Lenz. The only different is that lens has brought in a sign a negative sign.

TEACHER: Is opposite.

FACILITATOR: It opposes the original magnetic force. That's how the negative comes in. Sometimes it is because we look at the equation for Lenz and faradays like is the same equation, it is but Lenz was just adding the direction on faradays law, or faradays works.

TEACHER: Is the same ...

FACILITATOR: It is?

FACILITATOR: It oppose the direction of the flux that induced it, it will oppose it right? That why, even the definition if you listen to the definition they will tell you the same explanation. I will show the simulation.

ELECTRIC CURRENT AND THE MAGNETIC FIELD

FACILITATOR: **Slide 34**, flux is equal to $= B A$, what is B?

TEACHER: Magnetic field.

FACILITATOR: Magnetic field. But the magnetic field crossing a certain area, (*demonstrating*) can we look at this one first, I wanted a bigger solenoid. I'm increasing my solenoid right this is my solenoid. The area also is affecting the flux, and the field is also affecting the flux, remember the first time I said; we have the weak one (field), then it becomes strong; it becomes strong so the flux depend on what? On the strength of the magnetic field, we agree?

TEACHER: Mm.

FACILITATOR: But the flux also depends on the area at which it covers it. (*Demonstrating*) So if we look at this one is like as you push it in. I hope you will understand what a trying to do here. So as you push look at this part is covering up to this part (area), as you push it further this part is covered (*trying to explain and demonstrating*).

TEACHER: Mm...

FACILITATOR: (*Demonstrating*) as you push it into, the rest is like they are spreading to the side and they are cutting across, even going over the conductor as you push it inside. It covers the bigger area, the magnetic flux cover the bigger area when pushing it.

TEACHER: So magnetic flux is increased when we push in the magnet?

FACILITATOR: When we push in the magnetic, yes (*Nodding the head*).

FACILITATOR: For it to cover the bigger area, you should push it inside. So area is one of the factors that will affect the magnetic flux, that why we have BA . This is the part, the flux it's actually directly in proportional to the magnetic field, and the flux is also directly to proportional to the area it covers. The more area the field covers, the more the magnetic flux, so if we combine the two, (*showing on the board*), flux is equal to $\Phi = BA$, right, and now this is actually the change in magnetic flux.

The magnetic flux is changing because the magnetic field is changing. Flux is changing because the area which the magnetic field covers is changing, so this is the change in magnetic flux, right. So as we change this magnetic flux, what do we get? We induce the emf.

TEACHER: Yah, it makes sense, a relative movement will always change the magnetic flux.

FACILITATOR: (*Agreeing*).

TEACHER: Yah.

FACILITATOR: As the magnetic flux changes, we induce the voltage, the emf, and hence the current. So we induce, we get the emf because we are changing the magnetic flux, right! When we change the magnetic flux, we have the emf, right! I'm bringing in the equation now.

TEACHER: Mm.

FACILITATOR: Step by step! The emf! But then the strength of emf that is induced depend on what? On the speed at which at you change the flux.

TEACHER: Yah.

FACILITATOR: If you push it inside quickly, the reading will be like more, if you push it slowly, the reading or the voltage will be less. So the emf, strength of the induce emf, depend on what?

TEACHER: Change in flux.

FACILITATOR: On the rate (*emphasizing*) of change of flux. The faster you push magnet inside or the faster you pull out, either the magnet or the conductor, the faster you push or pull, the more the induced the emf. The slower you push the less the induced emf. So also time is really important for the induce emf that you need to get.

TEACHER: Mm.

FACILITATOR: So that why we say, the induce emf is actually depending on the rate, remember the rate of change of flux, will give you the strength of the induce emf (emf is symbolized by E).

TEACHER: Yah.

TEACHER 2: 'Madam', for the change in magnetic flux, we should also consider the angle between the magnetic..., the area.

FACILITATOR: The area?

Arguments

TEACHER: The area covered by the coil.

FACILITATOR: So this is the same, actually this is the same, as BA or $\Delta\phi$, the area covered by the field, called the flux, or the rate at which you change that flux.

TEACHER: Yah.

FACILITATOR: It will give, you the....

TEACHER: What we should not forget is that the magnetic flux, and the angle, must be taken into consideration, because the angle is the one that will bring the change in flux.

FACILITATOR: Will come to that as well. I am bringing the equation step by step, so we end up understanding how did we come to the full equation.

TEACHER: Mm

FACILITATOR: Right. Now the change in magnetic flux, there are factors like, the rate at which you change the flux, one other thing is also the angle like you said. Because the angle, (*demonstrating*) I am going to use this as my magnet this is my magnetic flux. This is my magnet ok? With the magnetic field, we cannot see the field; we can only see the magnet.

So I'm going to demonstrate, as this is my magnet, this is my field going out at the North Pole or at the South Pole right. This is my coil; I want to show now the issue of the angle because it also affects what? The induce emf.

TEACHER: Mm.

FACILITATOR: So what is the first thing that affects the strength of voltage? The rate at which you change the flux, right! The other thing ok, I am just going to make one loop. (*Demonstrating*) This is my loop, this is my magnet, and this is my magnetic field right! Now look at the surface of the field, the normal as we were saying yesterday is perpendicular to the field, right! So if a normal is perpendicular to the field, if we push it, (*demonstrating*) is like all the field is getting into the solenoid right.

But then remember there must be change, right. So if is like this (*demonstrating*), is like all the field (*using a shoe brash to represent the flux*) is getting in, but there's no movement at the moment because the field is steady. So when there is no movement there is no emf, remember. (*Demonstrating*) So if is like this all the field is getting to into this. But if this start to move, you must imagine our normal being at centre of the coil right. Now I start my movement (*demonstrating*), because there must be change for the voltage to be induced, right. Now I move (*demonstrating*),

lets' move the coil; we can move the coil or the magnet. Ok, so lets' rotate the coil, if I rotate the coil, I am moving it like this (*demonstrating*), right.

Where is the normal? The normal is facing (*demonstrating*), it makes the angle. Now look, first look at how much flux was getting in? If it goes like this, how much flux is going in? If it goes like this, how much is going in? If it is like this now, the magnetic field is parallel to the conductor.

TEACHER: Mmm.... (*Doubting*)

Argument....

FACILITATOR: Is parallel to the conductor, and remember yesterday saying when the current flows in the magnetic field, and moves parallel to the magnetic field, we said; It will not experience the force.

TEACHER: Yah.

FACILITATOR: Remember? Now if we push the magnetic field in the conductor there will be a movement, movement of charges.

TEACHER: I have a problem Ma'am which side. . .? (*For parallel and vertical side*)

FACILITATOR: This is my coil (*demonstrating*), according to this one, lets' talk about this one, (*demonstrating*) is this is vertical, or horizontal if it is like this?

TEACHER: The coil is vertical?

FACILITATOR: The coil is vertical.

TEACHER: Yah.

FACILITATOR: Magnetic field is going perpendicular, perpendicular and remember we said; if perpendicular it gives us a maximum voltage, right. Now if we rotate, this (flux) is going in (*demonstrating*), when I rotate, only this is going in, when I rotate only this is. When is parallel (coil), nothing is getting into the coil.

Now this time I'm not pushing inside, the movement is not going like, (*not pushing the coil in an out, but rotating the coil*). The movement is now rotation of the coil. When the coil rotate it means the whole magnetic field will start changing because of the angle, it's like decreasing from zero to ninety (90) and to zero again. So the area covered by the magnetic field is this, when it rotate only less area is covered. Up until we have the coil parallel to field, no magnetic field is induced.

TEACHER: That's where the problem is, in short, I think the confusion is when the magnetic field is parallel to the coil, the force is zero.

TEACHER: The EMF is maximum, and when the coil is perpendicular to the magnetic field, the force is maximum and the EMF is zero because, (BA) which is magnetic strength, is multiplied by the area covered by loop, $\cos 90$ ($BA \cos 90$)

FACILITATOR: Lets' talk about the angle.

TEACHER: So the two, the force, you talked about the force and the emf.

FACILITATOR: Lets' talk about the angle.

TEACHER: Yah!

FACILITATOR: What is the angle that we referring to? We are talking about the angle between the magnetic field and the area that is being covered.

TEACHER: Yah. There is a problem on position of the coil, I am seeing on page 08 here (*referring to the slide*).

FACILITATOR: We are on page 06 of slide. Creating a current using a magnet, do you hear the statement is saying? How do we create a current using the magnet?

TEACHER: Mm ?

FACILITATOR: This time we create current, but there is no power, but current is being induced. Now how are we inducing the current? We use the magnet to create that current. We can induce the current by moving a magnet inside a coil or vice versa right. This is called electromagnetic induction. A current can only be induce by

the change in magnetic field, in the magnetic the magnet remains in one position inside the coil, no current will be induced. Do we agree on that one?

TEACHER: Mm.

FACILITATOR: Voltage it is induce by the relative motion between a wire and magnetic field. Whether it moves near the stationary conductor or vice versa voltage it induced, either way, that one is fine?

TEACHER: Mm.

FACILITATOR: The greater the numbers of loops of wire cutting across the magnetic field, the greater the induced voltage. Now we were talking about factors affecting induce voltage right. So the more the numbers of turns the more the magnetic field crosses many turns (*demonstrating*).

TEACHER: Mm.

FACILITATOR: Right, so current or moving charges, also increases. Pushing the magnet at the same speed into the coil with twice as many loops, induces twice as much the voltage. That more numbers of turns will increase and the flux that will be crossing the conductor (solenoid) having more loops, so it (flux) will be crossing many loops and more current / many charges will flow.

So will have more current, if more charges are flowing in a solenoid, more current (Page 07, now). The emf induced in a coil is proportional to numbers of loops in coil and the rate at which the magnetic flux changes in loop. In other words the faster you push the magnet through the coil, the greater the induced emf. Now the equation

$$E = - \frac{N\Delta\Phi}{\Delta t}$$

TEACHER: Yah.

FACILITATOR: Then we can bring in an angle because an angle also gives us the strength of the voltage that has been induced. How does the angle bringing the changes in strength? The angle change the strength because the magnetic field that is getting there as you flip your coil, it means the whole magnetic flux that was

getting in is starting to decrease, up until the time when we don't have any magnetic flux getting into the coil.

If we have the magnetic flux at 90° with the coil, we'll have the maximum induced voltage. Now when we start, to rotate it means the whole magnetic field that was getting into the coil before is no longer getting into the coil. So less of the magnetic flux is crossing the conductor, right. Up until the time when they are now parallel to each other. Now when they are parallel to each other it means no induced EMF. So the flux is now zero at that point. The induced emf is zero. $\cos 0$ is zero at that point.

FACILITATOR: When the coil is perpendicular to the field (*demonstrating*), the coil is like this!, the field is like this! This is the situation.

TEACHER: The emf is zero but the force is maximum, when the coil is perpendicular, but the emf is induced, is zero, because of it should say; magnetic field multiple by the area covered by the coil $\cos$ of 90 , that 90 irrespective of direction you get $EMF=0$ but the force will be maximum.

TEACHER 2: This force is the movement of the charges.

FACILITATOR: of the charges? (*Facilitator missing the point*)

TEACHER: Madam! The other time I saw...; they said if the coil is like this neh! (*teacher trying to demonstrate*).

FACILITATOR: Mm...

TEACHER: We have ?

FACILITATOR: maximum induced emf!

TEACHER: No, is zero emf, is zero, but then I...

FACILITATOR: The emf is zero?

TEACHER: Yah.

FACILITATOR: No!

TEACHER: Is zero!

FACILITATOR: (*demonstrating*) before it was like this, if you push it inside, voltage it is induced, voltage is induced, and this is at 90° .

TEACHER: The position there is not (*disagreeing*), the angle is between the magnet and the coil ...

FACILITATOR: Yes the field and the coil; that's true.

TEACHER: What are the effects of this force?

FACILITATOR: It produces movement.

TEACHER: The explanation I got 'Madam', was that, when...

TEACHER: The field is to north not to south.

FACILITATOR: When the coil is vertical, which is being perpendicular to the magnetic fields of the bar magnet or the normal to the conductor being parallel to the field, then the EMF value will be maximum. Then when the coil is parallel, the opposite will apply, and the EMF induced in the coil will be zero

