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A self-study on learning and teaching electromagnetism in grade 11.

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2012-02-15
http://hdl.handle.net/10539/11322

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CHAPTER 1

INTRODUCTION TO THE STUDY

This chapter looks at the background to the study and puts into perspective the need to conduct the study. The rationale for the study looks at the reasons for conducting the study in order to indicate the general importance of the issue under discussion within the field of science education and its potential contribution to the community at large. The aim of the study highlights what the study hoped to achieve and the research problem brings to light the reasons why the focus of the study will be within the topic on *electromagnetism*. The chapter concludes by stating the research questions and indicating the limits within which this study is confined.

1.1 Background to the study

The Centre for Development and Enterprise (2007), a research group that provides South African decision-makers with detailed analyses of key national policy issues, reports that the South African schooling system continues to produce far fewer passes in mathematics and sciences than the country's economy requires. The Centre for Development and Enterprise (CDE) attributes some of the reasons for poor learner performance to the demands of the new curriculum and lack of adequate content knowledge (CK) by teachers regarding the learning and teaching of these subjects.

The new National Curriculum Statement Grades 10-12 (General) Physical Sciences is based on nine principles which are embedded in the Constitution of the Republic of South Africa. These principles are social transformation; outcome-based education; high knowledge and high skills; integration and applied competence; progression; articulation and portability; human rights, inclusivity, environmental and social justice; valuing indigenous knowledge system; and credibility, quality and efficiency (Department of Education (DoE), 2003).

The new curriculum (DoE, 2003) envisages a learning environment that is learner-centred and void of any issues that promote social injustice. The curriculum also envisages a learning environment that uses activity-based approaches to learning that

value indigenous knowledge systems as well as create environmental awareness. Central to the curriculum is the new approach to assessment. The curriculum expects teachers to use various forms and different types of assessment on a continuous basis in order to assist learners achieve the required learning outcomes.

These principles have put a huge demand on the curriculum such that teachers now do not only have to contend with the content of the subject, but also with all these principles in their teaching practice. Teachers are now expected to relegate some of their old ways of teaching such as teacher-centred approach and ways of assessing learners to accommodate the new roles stipulated by the Norms and Standards for Educators set out by the new curriculum. Teachers now have to fulfil various roles which include being mediators of learning; interpreters and designers of learning programmes and materials; researchers and lifelong learners; assessors; and subject specialists (DoE, 2003). These roles require teachers who are qualified and who can exhibit high levels of competency in their subject.

The National Curriculum Statement Grades 10-12 (General) Physical Sciences Content document outlines the structure and depth of the core knowledge to be covered in these grades (DoE, 2006). The new curriculum is an amalgamation of the old syllabus and new topics that have been introduced. Contents of the old syllabus were reviewed and restructured, and new topics were incorporated so that the new curriculum could meet the demands of the new era of learning. The restructuring of the old syllabus and the introduction of new topics resulted in a long, challenging curriculum which meant that teachers had to discard or adapt their old ways of teaching as well as learn to cope with the new topics that have been introduced.

The curriculum is structured so as to promote the spiral approach to learning and teaching (DoE, 2006). This new approach to learning and teaching is based on two principles which are conceptual progression and conceptual coherence. Conceptual progression fosters the gradual learning of concepts over a period of time, where concepts are first introduced in a grade and later revisited in the grade or later grades to promote a more understanding of the concepts. Conceptual coherence pertains to the linking of concepts with other related concepts in the grade or other grades as well as in other fields where they are applicable. The introduction of the spiral approach as

a vehicle to integrating learning meant that teachers had to have adequate knowledge of other subjects in order to link Physical Sciences to these subjects.

Unfortunately, these challenges have not been met with success. Many science teachers in South Africa still lack the adequate CK and knowledge of pedagogy required to meet the demands of the new curriculum. Rollnick, Bennett, Rhemtula, Dharsey and Ndhlovu (2008) report that figures recorded in 1998 by CDE show that less than 40% of Physical Sciences teachers nationally have a degree in any discipline, including science. Rollnick *et al.* further report that the majority of grades 10-12 science teachers prior to 1994 generally held a 3-year diploma that included CK equivalent to one year university physics and chemistry. Although some of the teachers have since improved their qualifications, they have done so in other disciplines such as education rather than in content areas (Rollnick *et al.*, 2008).

1.2 Rationale for the study

Sağlam and Millar (2006) argue that most studies that have been conducted within the field of electricity and magnetism have tended to focus on electricity separately from magnetism. They also argue that only a few studies have been conducted on the topic on *electromagnetism* even though both teachers and learners regard this topic as difficult to comprehend. Most of the studies that have focused on *electromagnetism* have tended to focus on learners' understanding of the concept of *electromagnetism* at tertiary level than at high school level. Thus, their study looks at the misconceptions commonly held by high school learners.

Few studies, such as the one conducted by Anderson and Mina (2003), have focused on how teachers can learn to teach the topic on *electromagnetism*. Anderson and Mina's study looks at a new approach to teaching *electromagnetism* at tertiary level rather than at school level. In this study, I seek to learn more about the topic on *electromagnetism* as well as explore better ways of teaching this topic to high school learners. Learning more about the topic on *electromagnetism* will enable me to develop an adequate pedagogical content knowledge (PCK) regarding its learning and teaching.

Van Driel, Verloop and de Vos (1998) maintain that teachers with well-developed PCK are likely to have better teaching strategies that will enable them to transform their subject matter knowledge into knowledge understandable to their learners. Teachers with well-developed CK and pedagogical knowledge are likely to have better ways of transforming the subject matter, teaching strategies that are most likely to promote learner understanding as well as ways of identifying and addressing learners' learning difficulties (Shulman, 1986).

This study hoped to contribute to the field of research in science education in that it intends to share the knowledge that will be gained with other researchers and teachers who are interested in understanding the developing of PCK on *electromagnetism*. Loughran, Berry and Mulhall (2004) argue that much of teacher knowledge is elusive as it is an internal construct. The tacit nature of teacher knowledge makes it difficult for this knowledge to be articulated and shared across the profession. Thus, one way of sharing this knowledge is to document it so that other teachers can access it.

The CDE (2004) reports that the mathematics and science education system continues to produce only a fraction of skilled Senior Certificate graduates required to meet the country's needs and that mathematics and physical sciences learners in South Africa consistently perform the worst in comparison with learners in other developing countries. This study hopes to assist teachers in better understanding the topic on *electromagnetism* so that they can enhance the understanding of it by their learners. Understanding the topic will enable learners to pursue careers in fields such as engineering, astronomy and medicine that the country so desperately need.

1.3 Aim of the study

The aim of the study is to:

- develop my PCK regarding the learning and teaching of *electromagnetism*.

1.4 Research problem

The introduction of Curriculum 2005 in South African schools has brought with it many changes regarding the learning and teaching of the knowledge area Electricity

and Magnetism. Topics that were previously taught under this knowledge area in grades 10-12 in the old syllabus were reviewed, restructured, and amalgamated to form the new knowledge area of Electricity and Magnetism. New topics such as electromagnetic induction in grade 11 and electrodynamics, electronics and electromagnetic radiation in grade 12 were introduced under this knowledge area. Although I have taught some of these topics in the old syllabus, the changes brought about by Curriculum 2005 made me realise my lack of sufficient PCK regarding the teaching of the topic on *electromagnetism*, which is taught in grade 11. My lack of adequate CK regarding *electromagnetism*, misconceptions associated with the topic, the abstract nature of the topic itself and lack of exposure to literature associated with its teaching have prompted me to embark on a self-study on how I can better learn to teach this topic to my learners and share the knowledge gained with other interested teachers and researchers.

1.5 Research questions

This study addressed the following questions:

- How does my CK develop as I learn the topic on *electromagnetism*?
- How does my PCK develop as I teach the topic on *electromagnetism*?

1.6 Delimitation of the study

This research project is a self-study in learning to teach a topic on *electromagnetism* to grade 11 learners. *Electromagnetism* focuses on the following sub-topics: (1) magnetic fields associated with electric current; (2) current induced by changing magnetic field (electromagnetic induction); (3) transformers; and (4) the motion of a charged particle in a magnetic field. Due to the diverse nature of the topic *electromagnetism*, only the sub-topic on electromagnetic induction (EMI) was chosen as the focus of this study. This sub-topic was also chosen on the basis of its abstract nature and my lack of CK and teaching strategies regarding its teaching.

The study was conducted at an informal settlement in Gauteng at a school in which I teach. Only one class of three grade 11 classes who take Physical Sciences in this

school was used for the study. The reason to use this class was based on the fact that this is the only class that I teach in grade 11 and using the other classes would disrupt the teaching time and extra-class programmes of other science teachers who conduct these programmes in the afternoons. Thus, only 26 learners of mixed gender took part in the study.

The study is confined to the development of my PCK required to learn to teach the topic on *electromagnetism*. Various sources were consulted in order to assist me in acquiring a well-developed CK and pedagogical knowledge to improve my teaching practice. These sources included the National Curriculum Statement (Grades 10-12) for Physical Sciences document; Physical Sciences Content (Grade 10-12) document; journal articles on *electromagnetism*, PCK, self-study and metacognition; and textbooks (Grades 10-12 and first year tertiary textbooks). The Rollnick *et al.*'s (2008) theoretical framework was used to focus on those aspects of learning and teaching that seek to develop my teaching practice.

Chapter 2 reviews the literature that supports the basis for the study. The chapter also details the literature on the development of the topic on *electromagnetism* and its challenges with regards to its learning and teaching. In the chapter, I also address teacher knowledge with a view of establishing the location of the study within the current debates that are taking place in science education. A theoretical framework which drives the purpose for the study is also discussed. The chapter concludes by discussing metacognition as a teaching strategy used to reflect on learning.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Shulman (1986) observes that teaching has long been a borne of contention among education researchers. This controversy has been raging on for more than a century due to past educational reforms placing more emphasis on certain aspects of teaching at the expense of others. In his Presidential address paper presented at the 1985 annual meeting of the American Educational Research Association in Chicago, Shulman explains how educational reforms have evolved over the last two centuries and how these reforms have tended to undermine the complexities of teaching as an enterprise. At the centre of his argument is the way these reforms have tended to divorce content knowledge from other aspects of pedagogical practice.

His examination of educational reforms prior to 1870s shows that content knowledge and knowledge of pedagogy were part of one indistinguishable body of teacher knowledge. Teachers were expected to demonstrate high levels of competence in both content knowledge and knowledge of pedagogy to qualify for teaching. Educational reforms that took place in the 1870s emphasised the importance of content knowledge at the expense of pedagogical knowledge. Any person, who demonstrates high knowledge of the content to be taught and less knowledge of the theories and methods of teaching, was legible to teach after having passed his or her qualification examination in teaching.

Shulman (1986) observes that reforms on teaching in the 1980s have tended to focus more on classroom practice with far less emphasis on content knowledge. These reforms put more emphasis on classroom management, organisation of activities, planning of lessons and learners' assessment ignoring the important aspect of classroom existence which is content knowledge. Shulman notes with dismay that content knowledge is only considered a context variable in research on teaching and that no research has focused on content knowledge itself as one important aspect of

teaching. He refers to the absence of content knowledge in research on teaching as a missing paradigm.

Studies by van Driel, Verloop and de Vos (1998) reveal that research on teaching conducted from the late 1980s into the 1990s have tended to redress the imbalances of putting a sharp distinction between content knowledge and knowledge of pedagogy. These studies are focusing on aspects of teacher knowledge that blend content knowledge with knowledge of pedagogy. Explicit in these studies is the realisation that teachers need to have a good background of the content they teach as well as knowledge of the pedagogy for effective teaching and learning to take place. Also relevant in these studies is the approach undertaken by recent research to better understand how teachers transform their expert knowledge of the content into knowledge comprehensible to learners.

This study upholds the approach undertaken by recent research on teaching as I believe that it will assist me in addressing the research questions set forth in chapter one of this study. The approach will enable me to focus on those aspects of content knowledge on *electromagnetism* which I need to develop in order to have a better understanding of the topic. This approach will further assist in identifying those aspects of teacher knowledge that will help develop knowledge of pedagogy most relevant to the teaching of this topic. This approach also assists in establishing a theoretical framework which will drive this study. Metacognition was drawn in this approach as a learning strategy in reflecting on my learning. Thus, the following sections of this chapter review literature on *electromagnetism*, teacher knowledge, theoretical framework and metacognition.

2.2 Electromagnetism

2.2.1 The historical background

Electromagnetism is defined as a branch of study that deals with magnetic forces produced by electric current and the electric effects produced by magnetic fields (Hartmann-Petersen, Gerrans & Hartmann-Petersen, 2002). This branch of physics integrates two fields, namely electricity and magnetism. According to Giancoli

(2005), these two fields were first treated as separate until in 1820 when Hans Christian Oersted showed that an electric current produces a magnetic field. Shortly afterwards, Michael Faraday and Joseph Henry independently showed that electric currents could be produced by moving a magnet relative to a wire. Since these discoveries, electricity and magnetism have been closely related and their relationship has led to the birth of *electromagnetism*.

Anderson and Mina (2003) argue that James Clerk Maxwell was the first to conceptualise *electromagnetism* in 1873 when he proposed that *electromagnetism* was made of fundamental concepts, mathematical formulations and a set of observed phenomena. According to them, Maxwell explained that mathematical formulations could be used to manipulate the fundamental concepts governing *electromagnetism* in order to explain the observed phenomena. They also observed that in the early twentieth century, Olivier Heaviside and Heinrich Hertz introduced vector calculus in *electromagnetism* in an attempt to make it more applicable and powerful. However, the introduction of vector calculus has resulted in *electromagnetism* being heavily mathematical, leaving conceptual understanding behind (Anderson & Mina, 2003).

The structure of *electromagnetism* has remained the same since its conceptualisation by Maxwell (Anderson & Mina, 2003). However, *electromagnetism* as a branch of study has since developed into many sub-branches. This field of study is now divided into other sub-branches such as electromagnetic induction, electrodynamics, electromagnetic waves, and electromagnetic radiations, which exist as independent fields (Anderson & Mina, 2003). The rapid development of *electromagnetism* has also had an impact in other branches of physics. Topics such as light, sound, waves, quantum mechanics and electronics are now better explained using the concepts and laws of *electromagnetism*. The concepts and laws of *electromagnetism* are also applicable in other fields of study such as astronomy, biology, chemistry, geography and medicine.

2.2.2 The learning and teaching of electromagnetism

Anderson and Mina (2003) suggest that the approach to teaching *electromagnetism* has not fundamentally changed since the days of Maxwell. The topic is still divided into three major sections, which are fundamental concepts, mathematical formulations

and observed phenomena. The topic is highly conceptual, phenomenological in nature, and full of mathematical approaches and proofs meant to better explain the fundamental concepts and the observed phenomena. The topic is still as abstract and complex as it was in the early twentieth century (Anderson & Mina, 2003).

Anderson and Mina (2003) have identified three main goals of teaching *electromagnetism*. The first goal is to teach learners concepts, basic equations and mathematical formulation in order for learners to see the importance and application of the laws of *electromagnetism*. The second goal is to teach learners how to use models in order to solve realistic problems and to give them the ability to examine results, answers and expected outcomes based on fundamental concepts. The third goal is to show learners that by using abstract concepts with the right mathematical tools one is able to examine, explain and formulate practical applications.

Anderson and Mina (2003) have identified two methods of teaching *electromagnetism*. These are the traditional approach and the new approach which they are recommending. The traditional approach teaches learners the fundamental concepts and basic mathematical formulation so that learners can apply these to solving realistic problems. The new approach decouples advanced mathematics from the topic and focuses on teaching the fundamental concepts by first using less sophisticated mathematics. Once the learners have mastered the concepts they are then introduced to computer programmes that help them to learn by discovery and inquiry the mathematical and computational parts of the topic. The new approach suggested by Anderson and Mina is however meant for learners at tertiary level other than those at school level.

Sağlam and Millar (2006) do implicitly mention an instructional approach recommended for high school learners by Bagno and Eylon (1997). Bagno and Eylon propose an instructional approach which requires learners to develop concept maps in order to summarise their ideas about *electromagnetism* and the links between them (Sağlam & Millar, 2006). Anderson and Mina (2003) report that other approaches to teaching *electromagnetism* still employ the traditional way of teaching but use many tools such as computer-aided programmes to help learners visualise the phenomena associated with the topic.

Schwartz and Sadler (2007) compared three different approaches of teaching *electromagnetism* to grade 7 and grade 8 learners. These are traditional, discovery and Doable Engineering Science Investigations Geared for Non-science Students (DESIGNS) approaches. Their study explored the impact on learning and teaching when teachers and learners are differentially empowered. Their study recommended the DESIGNS approach as this approach attempts to balance curricular responsibilities between teachers and learners. They believe that the DESIGNS approach provides classroom environments that offer both teachers and learners opportunities to share decisions in choosing learning goals and/or the strategies to reach those goals.

Schwartz and Sadler (2007) believe that the traditional approach allows learners too little control over the choice of learning goals and strategies to reach those goals. They argue that in this approach, the textbook is primarily responsible for determining goals, strategies for reaching goals and the sequence of activities. The approach restricts learners to learn by doing as the procedures followed are aimed at reproducing results expected by the textbook and the teacher. According to Schwartz and Sadler, the approach fails to produce significant knowledge gains as the order of skills development proceeds from abstractions (lecture and demonstration), to representations (worksheets) and ends with action (laboratory practical), which is opposite to that of the DESIGNS approach.

Schwartz and Sadler (2007) further argue that the discovery approach allows learners too much control over the choice of determining learning goals and the strategies to reach those goals. They acknowledge that this approach does lead to significant knowledge gains as learners get the opportunity to challenge their beliefs by deciding on the alternative goals and the learning strategies they wish to explore. They however argue that allowing learners too much freedom to choose the learning goals and pursue their own strategies for reaching those goals result in learners failing to recreate or understand the principles that the teacher wants them to learn. Too much freedom result in learners taking more time to reach the intended learning goals and this makes the classroom environments difficult to manage without curricular or administrative support.

The South African Curriculum 2005 does not explicitly prescribe the learning and teaching methods that teachers need to employ to help learners reach the intended learning goals. The curriculum however, rejects the traditional approach as this approach advocates classroom environments that are teacher-centred. The curriculum encourages classroom environments that are activity-based and learner-centred. Such environments are viewed as practices of the discovery approach as they allow learners control of choosing learning goals and strategies to reach the intended learning goals. However, the curriculum also stipulates that teachers need to be the interpreters and designers of learning programmes and materials in such environments. Such expectations suggest that the curriculum does welcome the DESIGNS approach as this approach advocates the sharing of curricular responsibilities between teachers and learners to attain the intended learning goals.

This study adopts the DESIGNS approach suggested by Schwartz and Sadler (2007). Both teachers and learners should be part of curricular decision-making that identifies learning goals and procedures to be followed to reach those goals. The study also realises that the accomplishment of such goals is influenced by the learners' growth development and the degree of the environmental support they receive as suggested by the DESIGNS approach. The study also supports the approach suggested by Sağlam and Millar of using concept maps as a learning strategy. However, concept maps in this study are used primarily as a learning strategy by the teacher and not by the learners. In this study, concept maps are also used by the teacher in the classroom environment as constant reminder of the lessons' goals and to help learners generate constructive feedback.

2.2.3 The content of electromagnetism

Sağlam and Millar (2006) have observed that many countries first introduce the topic of *electromagnetism* in upper high school physics curriculum. Their analysis of the content of *electromagnetism* at high school level in Turkey and England reveal that the topic can be subdivided into three broad sections. These sections are: (1) magnetic fields caused by moving charges; (2) magnetic forces on moving charges and current-carrying wires, and (3) electromagnetic induction. Electrodynamics forms part of the curriculum in both countries since mention is made of sections such as motors and

generators in these curriculums (Sağlam & Millar, 2006). However, it is not clear if sections such as electromagnetic radiations and electromagnetic waves are treated as part of the whole topic of *electromagnetism* or are viewed as independent sections.

In South Africa, *electromagnetism* is first introduced in grade 11, one year before learners sit for their final examination at school level. The topic is introduced after learners have been exposed to electricity and magnetism separately in the preceding grades and in grade 11. According to the Physical Sciences Content document (DoE, 2006), *electromagnetism* forms part of the 12,5% of the knowledge area Electricity and Magnetism covered in grade 11. Introductory *electromagnetism* in grade 11 is divided into four sections. These sections are: (1) magnetic field associated with electric current, (2) current induced by changing magnetic field, (3) transformers, and (4) motion of a charged particle in a magnetic field (DoE, 2006). Sections such as 'current induced by changing magnetic field' and 'motion of a charged particle in a magnetic field' are new in the curriculum whereas, sections such as 'magnetic field associated with current' and 'transformers' were previously taught in the old curriculum in grade 12 and grade 10 respectively.

Electromagnetism is further revisited in grade 12 under the same knowledge area Electricity and Magnetism. The content document (DoE, 2006) stipulates sections such as electrodynamics and electromagnetic radiation as a continuation of the topic on *electromagnetism*. Electrodynamics looks at how the effects of *electromagnetism* are used to explain the operation of electrical machines such as motors and generators. The alternating current concept is discussed as a result of its importance in generating a changing magnetic flux using transformers. The section on electromagnetic radiation looks at the dual (particle and wave) nature of electromagnetic radiation, electromagnetic spectrum, and the penetrating ability of different kinds of electromagnetic radiation and its relationship to the energy of the radiation. The content is highly conceptual, full of phenomena and mathematical formulations as observed by Anderson and Mina (2003) in their study.

2.2.4 Difficulties associated with the learning and teaching of electromagnetism

Sağlam and Millar (2006) observed that one big problem about the learning and teaching of *electromagnetism* is that its phenomena are not obvious part of learners' everyday life and discourse. Based on this observation, they argue that learners are therefore unlikely to have constructed many of the basic ideas of *electromagnetism* prior to instruction as most of these ideas can only be produced in the laboratory using sophisticated equipment. Most of the conceptions that learners experience at an early age and/or as they progress through schooling (before being introduced to *electromagnetism*) are those associated with electric and magnetic phenomena as separate entities (Thong & Gunstone, 2008). Thus, when learners are first introduced to *electromagnetism*, they are likely to come to class with no ideas or primitive ideas about *electromagnetism*.

The second problem associated with the learning and teaching of *electromagnetism* is that many learners are unaware that some of the ideas they have learned in other topics are applicable in *electromagnetism*. Sağlam and Millar (2006) maintain that a major part of learners' reasoning is content specific and this makes it difficult for them to transfer the ideas they have learned in other topics to *electromagnetism*. These problems are confirmed by Galili (1995) in Sağlam and Millar (2006) when he said that many learners are not aware, for example, that Newton's third law of motion is applicable in *electromagnetism* and that some learners have a difficulty applying the ideas about work and energy in contexts involving electric and magnetic fields. Sağlam and Millar suggest that learners' inability to link the ideas learned from other topics may be due to their incoherent frameworks they have built on these topics.

The third problem associated with the learning and teaching of *electromagnetism* is that this topic lends itself to many misconceptions from other topics associated with it. The topic is closely related to other topics such as electricity, magnetism, kinematics, dynamics, and quantum mechanics. Learners who have superficial and discrete ideas about the topics related to *electromagnetism* are likely to bring up those ideas when learning *electromagnetism*. Thong and Gunstone (2008) confirm this idea when they say that some of learners' learning difficulties in *electromagnetism* are as a result of the mismatch of knowledge transferred from other topics. Sağlam and Millar (2006)

suggest that these discrete ideas held by learners form incoherent knowledge frameworks which are too primitive and naïve to can be used to explain some of the concepts in *electromagnetism* which are abstract.

Maloney (1985) in Sağlam and Millar (2006) identified some of the misconceptions held by learners when learning *electromagnetism*. Maloney argued that many learners view magnetic poles as electrically charged, confuse electric and magnetic field effects, and have difficulty with the dependence of induced electromotive force (emf) on rate of change of another variable (e.g. magnetic flux or current) rather than its actual value. Thong and Gunstone (2008) identified other misconceptions held by learners about electromagnetic interactions. These are the induced current varies proportionately with current in a solenoid; there must always be contact between magnetic flux and external coil for an emf to be induced in the coil, and electrostatic potential difference is the same as an induced emf.

Sağlam and Millar (2006) identified four sources of misconceptions most prevalent during instructions at high school level. These are inappropriate use of analogies; an over-literal flow interpretation of magnetic field lines; incorrect use of direct cause-effect reasoning in situations where they do not apply; and confusion between change and rate of change of variables (such as in magnetic flux). Albe, Venturini and Lascours (2001) in Sağlam and Millar (2006) also identified that many learners have difficulty linking their conception of magnetic flux to the standard ways of representing it because most learners are unable to define magnetic flux or apply the formula to simple problem situations; and many are unable to draw a vector representation of a uniform magnetic field or use vector ideas to add two magnetic fields.

The other problem concerning the learning and teaching of the topic is due to the abstract nature of the topic itself. *Electromagnetism* is highly conceptual, full of mathematical formulations and phenomenal in nature. Most of the fundamental concepts and phenomena are really better explained using sophisticated mathematics such as vector-calculus, laboratory equipment and visualisations (Anderson & Mina, 2003). Sağlam and Millar observed that many textbooks use two-dimensional diagrams to represent situations of electromagnetic phenomena which are rather three-

dimensional. They believe that difficulty in visualising such situations may have an effect in their understanding of electromagnetic phenomena. The mathematics used at high school level does not really provide the necessary understanding required to come to grips with the concepts (Anderson & Mina, 2003).

This study supports the views held by the research literature discussed above. The study realises that some of the learners' learning difficulties stem from the inherent characteristic abstract nature of the topic and that most of the phenomena on *electromagnetism* are not obvious part of learners' everyday life. The study also acknowledges that learners are likely to bring to class alternative conceptions that are primitive and naïve as their conceptual frameworks of other related topics may be incoherent and fragmented. The study supports Sağlam and Millar's suggestions that understanding the misconceptions developed prior to and during instruction and having some insights into their origin may help develop more effective ways of learning and teaching the topic. The study also realises that using concrete modelling and reducing unnecessary mathematical jargon may significantly promote better conceptual understanding in the learning of *electromagnetism*.

2.3 Teacher knowledge

Van Driel *et al.* (1998) observed that much of the research conducted in science education differs on the nature and content of teacher knowledge. They acknowledge that much of teacher knowledge still needs to be discovered, invented and refined as suggested by Shulman (1987). Their study is based on the assumption that although most of the research conducted so far on teacher knowledge differs on some aspects of teacher knowledge, it somehow does identify with many elements of teacher knowledge broadly outlined by Shulman. Although their study is based on the development of PCK within science teaching, they reviewed studies conducted on teacher knowledge to establish a broad concept of teacher knowledge as viewed by many researchers.

Van Driel *et al.* (1998) define teacher knowledge as an integrated knowledge which teachers have as a result of their accumulated experience with respect to their teaching practice. According to van Driel *et al.*, teacher knowledge encompasses teachers'

knowledge and beliefs about various aspects of teaching such as pedagogy, learners, content knowledge and the curriculum. To them, teacher knowledge is derived from prior education as well as from ongoing schooling activities. Teacher knowledge is influenced by factors related to teachers' personal backgrounds and the context in which they work. According to van Driel *et al.*, teacher knowledge consists of seven categories as identified by Shulman. These categories are: CK, PCK, curriculum knowledge, general pedagogical knowledge, knowledge of learners and their characteristics, educational contexts, and educational purposes.

The purpose of this study is not to enter into debates about the nature and content of teacher knowledge but to explore one aspect of teacher knowledge that will assist in addressing the research questions set forth in the study. The study is following in the footsteps of a research that is attempting to record and organise the reasoning and actions of teachers into cases to establish standards of practice for particular areas of teaching as recommended by Shulman (1987). The study focuses on PCK as that aspect of teacher knowledge that will assist me in the development of my teaching practice with regards to learning the content on *electromagnetism* and developing teaching skills that are specific to teaching the topic. Van Driel *et al.* suggest that when dealing with content, teachers' actions are determined to a large extent by their PCK, making PCK an essential component of teacher knowledge.

2.3.1 Pedagogical content knowledge

Van Driel *et al.* (1998) argue that the concept of PCK was first introduced by Shulman. Shulman (1986) defines PCK as knowledge that goes beyond content knowledge per se to knowledge of content specially tailored for teaching. He describes PCK as a distinctive body of teacher knowledge that blends content with pedagogy. When interacting with content knowledge, teachers grasp the ideas, probe them, comprehend them, and shape and tailor them in such a way that they can be understood by learners (Shulman, 1987). Shulman refers to this rigorous interaction with ideas as the transformation of content knowledge into knowledge suitable for teaching. According to him, this kind of teacher knowledge is what distinguishes the content knowledge of teachers from that of content specialists.

Shulman (1986) describes PCK as a special form of content knowledge that represents aspects of content most relevant to its teaching. The aspects of content he refers to are useful ways of representing key ideas of the topic or content; learners' characteristics and their learning challenges; and topic-specific learning and teaching strategies. The ways of representation of key ideas he refers to are: analogies, demonstrations, examples, explanations, illustrations, to mention just a few. Learners' characteristics refer to the diverse backgrounds learners bring with them to the learning environment. Learning challenges refer to the conceptions that learners have to learn and understand as well as preconceptions that they are likely to bring to the learning environment. Topic-specific learning and teaching strategies refer to strategies that teachers have to employ to overcome and transform the understanding of learners.

In reviewing literature on science teachers' PCK, van Driel *et al.* (1998) observed that a number of studies indicate that teachers, irrespective of their teaching experience, show little PCK when teaching unfamiliar topics. These studies showed that experienced teachers rely on their wealth of general pedagogical knowledge to sustain the flow of their instructions while they quickly learn the new content, content-specific representations and instructional strategies. On the other hand, novice teachers rely on conventional representations and instructional strategies that stress procedures rather than learner understanding to maintain the flow of their instructions. These studies attributed this lack of PCK of novice teachers to their lack of teaching experience (van Driel *et al.*, 1998). Based on these observations, van Driel *et al.* concluded that teachers need classroom practice to transform their CK into knowledge that enhances learner understanding.

Van Driel *et al.*'s (1998, pp. 681-682) study of science teachers' PCK reveals a number of features regarding the development of PCK. Firstly, the study realises that teaching experience coupled with a well-developed knowledge of the content contribute positively to the development of PCK. Secondly, the study believes that general pedagogical knowledge constitute a supporting framework to the development of PCK. Thirdly, teaching experience is the major source of teacher knowledge that enhances the development of PCK. Fourthly, a thorough and coherent framework of CK acts as a prerequisite, preceding the development of PCK. Fifthly, PCK is topic-

specific and has limited transfer to other situations. Lastly, research on learner learning and teaching could also contribute to the development of teachers' PCK.

Another important aspect of PCK worth discussing is its tacit nature. Loughran *et al.* (2004) argue that PCK is a complex and interwoven notion which teachers find difficult to explicate as this notion is an internal construct. They maintain that the boundaries of PCK are blurry as its structure is not always clear and consistent. Loughran *et al.* also argue that PCK is difficult to articulate as most teachers lack a common vocabulary that is a construct of PCK to explicitly elucidate their PCK. They also maintain that many teachers are often unaware of the PCK they posses as this construct is often contextualised and associated with particular learners, events and situations. Teachers usually share activities, teaching strategies and clever insights with colleagues and teach a particular content in a particular way but rarely provide explicit pedagogical reasons as to why they do so. Teaching demands such as time and curricular management, and learner achievement also tend to create a focus on doing teaching rather than explicating the associated pedagogical reasons.

Loughran *et al.* (2004) argue that teachers' PCK may not be evident within a short period of time such as one lesson experience and as such need an extended period of time for it to be unfolded. They also allude to the fact that studies show that classroom observations can only provide limited insights into teachers' PCK. Hence, they suggest that another way of capturing teachers' PCK is to ask teachers to talk about it. In this way, teachers can be in a better position to articulate their PCK so that it can be documented and portrayed for others to can share their experiences. They suggest an approach to uncover, document and portray science teachers' PCK that comprises two instruments, namely Content Representation (CoRe) and Pedagogical and Professional experience Repertoire (PaP-eR). CoRes and PaP-eRs can be used both as a method of capturing PCK and as an approach to portraying this knowledge to others. CoRes and PaP-eRs are discussed in detail later in sections 3.6.3 and 5.2.

2.3.2 Various models of PCK

Shulman's model of PCK is probably the first model of PCK since Loughran *et al.* maintain that Shulman was the first to conceptualise the idea of PCK. This model

comprises three elements of PCK, namely knowledge of content representations, learner learning difficulties and their conceptions, and learning and teaching strategies. What is of particular note in this model is the exclusion of CK per se as a component of PCK. Shulman does not consider CK as a component of PCK but rather considers content representations as part of PCK. To him, CK is an unmodified, separate knowledge created by domain experts and this knowledge needs to be transformed first before it can be regarded as part of PCK. Shulman (1987) believed that CK should first be reorganised and adapted to the needs, interests and abilities of diverse learners before it can be presented for instruction.

Various models of PCK have emerged since Shulman conceptualised the notion of PCK. According to van Driel *et al.* (1998), these models were conceptualised by scholars such as Grossman (1990); Marks (1990); Cochran, De Ruiter and King (1993); and Fernández-Balboa and Stiehl (1995). Other models such as those of Geddis and Wood (1997); Bishop and Denley (2007); and Rollnick *et al.* (2008) have also emerged. Table 2.1 below summarises the conceptualisation of PCK as viewed by these scholars. Table 2.1 is an adaptation and extension of the Table that was constructed by van Driel *et al.* and includes the Geddis and Wood's model and other models post 1998. The Table shows how Shulman's model of PCK has been extended by the scholars to include other components of teacher knowledge since its inception.

Table 2.1: Knowledge components in different conceptualisations of PCK

Scholars	Subject matter	Representations and strategies**	Learner learning and conceptions	General pedagogy	Curriculum and media	Context	Purposes
Shulman (1987)	a	PCK	PCK	a	a	a	a
Grossman (1990)	a	PCK	PCK	a	PCK	a	PCK
Marks (1990)	PCK	PCK	PCK	b	PCK	b	b
Cochran *et al.* (1993)	PCKg*	b	PCKg	PCKg	b	PCKg	b
Fernández-Balboa & Stiehl (1995)	PCK	PCK	PCK	b	b	PCK	PCK

Geddis & Wood (1997)	b	PCK	PCK	b	PCK	b	b
Bishop & Denley (2007)	PCK	b	PCK	PCK	PCK	PCK	PCK
Rollnick *et al.* (2008)	PCK	b	PCK	PCK	b	PCK	b

a: distinct category in the knowledge base for teaching; b: not discussed explicitly.

*PCKg: means pedagogical content knowing as PCK was viewed by Cochran *et al.*

** Table 2.1 has combined Shulman's knowledge of representations, and understanding of learners' learning difficulties and conceptions as one aspect of teacher knowledge.

Table 2.1 shows that there is no universally accepted model of PCK as suggested by van Driel *et al.* Different scholars have extended the notion of PCK by adding or integrating other components of teacher knowledge to conceptualise their PCK. Scholars (those referred to in Table 2.1) seem somehow to agree about Shulman's key components of PCK. Those who differ consider either CK (Cochran *et al.*; Bishop & Denley; Rollnick *et al.*) or both CK and content representations (Marks; Fernández-Balboa & Stiehl) as the component of PCK. Although these models differ on the location of CK relative to PCK, studies show that researchers do however agree that: (1) a thorough and coherent understanding of CK acts as a prerequisite to the development of PCK (van Driel *et al.*, 1998), and (2) CK needs to be transformed into knowledge accessible to learners before it can be made available for instruction (Geddis & Wood, 1997).

Van Driel *et al.* (1998) maintain that scholars also seem to agree on the nature of PCK. According to van Driel *et al.*, scholars believe that PCK is to be discerned from knowledge of pedagogy, learner characteristics and educational purposes since PCK refers to particular topics. Scholars also maintain that PCK differs considerably from CK per se as it concerns the teaching of particular topics. Content knowledge needs to be transformed into knowledge that will address the needs of learners using topic-specific teaching strategies. Furthermore, van Driel *et al.* acknowledge that all scholars agree that PCK is developed through an integrative process that is embedded in classroom practice. It is in classroom environments that teachers can effectively develop their PCK because in such environments, teachers are better able to establish

learners' learning difficulties and to deploy better teaching strategies that will enhance their learning.

2.4 Theoretical framework

The Rollnick *et al.*'s (2008) model of PCK has been chosen for the purpose of this study. Its benefits for use in this study reveal several reasons. Firstly, the model highlights the role played by CK in developing the PCK of teachers. Secondly, the model shows how different aspects of teacher knowledge are integrated to produce the PCK of teachers. Thirdly, the model shows how the observable products of teaching in the classroom can be used to portray the PCK of teachers. Fourthly, the model is flexible in accommodating the many visible features of teaching displayed by teachers during instruction that can be captured and documented as teacher PCK. Fifthly, the model supports the idea that teacher PCK is developed in classroom practices as well as in ongoing teacher development. Furthermore, the model has relevancy to the South African context in that it is aware of the educational issues currently affecting the PCK of many teachers in the country.

The Rollnick *et al.*'s model (see Figure 2.1 below) classifies teacher knowledge into two broad categories called the domains and manifestations. The domains are four fundamental components of teacher knowledge which when amalgamated produce teacher PCK. These domains are drawn principally from the Cochran *et al.* model and include CK, knowledge of learners, general pedagogical knowledge, and knowledge of educational context. Manifestations refer to those aspects of teacher knowledge that are observable in the classroom situations. Manifestations demonstrate the extent of development of the teacher's PCK after the teacher has blended the four domains of teacher knowledge. Manifestations are drawn primarily from the Geddis and Wood's model and other observable products of teaching that are visible in the classroom situation. For this model, the manifestations are CK representations, topic-specific instructional strategies, curricular saliency and assessment.

The model shows that PCK is an integrative process involving the amalgamation of the four domains of teacher knowledge. In this model PCK is produced by combining sound knowledge of the content with knowledge of learners, educational context and

general pedagogy. Since PCK is tacit and difficult to articulate, manifestations are used as visible forms of PCK to demonstrate the extent of teachers' PCK during classroom practice. Teachers demonstrate the extent of development of their PCK when they use various forms of content representations, instructional strategies and assessment activities that are relevant in promoting conceptual understanding of the topic, as well as when they show the depth and breadth of the content (curricular saliency) they are teaching. Since the domains are sources from which PCK is derived and the manifestations are visible features of PCK in the classroom, the domains are regarded as the inputs of PCK and the manifestations as the outputs of PCK. The model connects teachers' observable practices to their knowledge domains and thus assists in interpreting and understanding the nature of teachers' PCK.

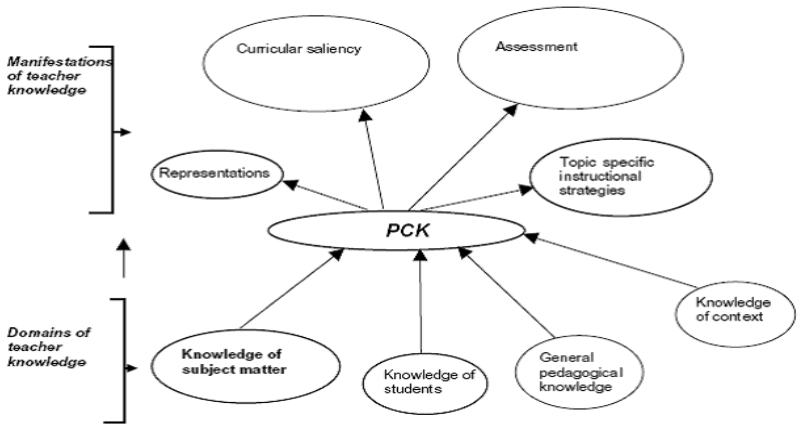


Figure 2.1: Rollnick *et al.*'s (2008) Model of PCK

Knowledge of subject matter refers to knowledge of the content as viewed by domain experts in a particular discipline. It refers to knowledge of concepts; laws; principles and theories governing that particular discipline as well as the structures of the content. Knowledge of learners refers to knowledge that learners bring to class, knowledge of their learning difficulties as well as knowledge of their capabilities, interests and aspirations toward the subject. General pedagogical knowledge refers to knowledge of basic skills required for teaching. These include knowledge of teaching strategies and methods, different learning theories, classroom organisation and management, physical and psychological behaviour of learners, and specific educational purposes. Knowledge of context refers to all contextual factors affecting teaching and learning (Rollnick *et al.*, 2008). These include factors such as the

availability of resources, socio-economic background of learners, classroom conditions, and time available for teaching and learning.

Subject matter representations refer to forms of representations used by the teacher to make the subject comprehensible to learners (Shulman, 1986). These include analogies, illustrations, demonstrations, examples and explanations. Topic-specific instructional strategies refer to approaches employed by the teacher to facilitate the course of the instruction. These strategies include methods the teacher employs to sequence the lesson, questions asked to assess progress as well as learner activities provided to direct the course of the lesson. Curricular saliency refers to teacher knowledge of depth and breadth of the curriculum. This teacher knowledge includes knowledge of how a particular topic links with other topics within and outside subject domain as well as awareness of which things to include or exclude in the lesson to help learners comprehend the topic. Assessment is a process of collecting and interpreting evidence in order to make judgement on learners' competences (DoE, 2006). There are various forms of assessments. These include: baseline, diagnostic, formative and summative assessments.

In this study, the Rollnick *et al.*'s model was used to analyse instruments such as concept maps, CoRe and PaP-eR, and video recorded lessons that I presented. The model assisted me in capturing the domains and manifestations which emanated from these instruments. These domains and manifestations portrayed aspects of my teacher knowledge which defined the nature of my PCK.

2.5 Metacognition

Georghiades (2004) reviewed literature based on the concept of metacognition over the past three decades. He discovered that most of the literature he reviewed refers to metacognition as the ability to think about one's own thinking. According to his findings, metacognition is usually related to learners' knowledge, awareness and control of the processes by which they learn. He also discovered that some of the literature identified two essential features of metacognition, namely self-appraisal and self-management. Self-appraisal refers to reflection about one's understanding, abilities and affective state during the learning process whereas self-management

refers to mental processes that help one to coordinate aspects of problem solving (Georghiades, 2004).

In an attempt to describe the nature of metacognition, Georghiades first distinguished between cognition and metacognition. He defined cognition as the actual processes and strategies used by one to facilitate learning and metacognition as knowledge about these processes and the ability to monitor or control them. He then went on to identify two types of metacognition, namely metacognitive reflection and metacognitive monitoring. According to him, metacognitive reflection refers to the critical revisiting of the learning process with a purpose of establishing the procedures followed, acknowledging mistakes made on the way, identifying relationships and tracing connections between prior understanding and new knowledge. He defined metacognitive monitoring as reflective feedback that requires an element of judgement that is essential in comparing, assessing and evaluating the process of one's learning.

Georghiades (2004) maintains that metacognition has found its way in science education as a way of facilitating and monitoring one's learning processes. According to him, research conducted on learning with regards to metacognition suggests that: (1) self-conscious learning can be enhanced if one is afforded the opportunity to reflect on his/her own thinking or conscious experiences; (2) one operates best when one has insight into his/her own strengths and weaknesses and access to his/her repertoire of learning; and (3) one can gain control or mastery over his/her own learning if one can bring the processes of thinking and learning to a conscious level. These findings imply that metacognition can be introduced in learning as a way of developing one's self-knowledge and as the ability to learn how to learn.

According to Georghiades, research done on teaching with regards to metacognition suggests that: (1) metacognitive theories can assist teachers to construct classroom environments that focus on flexible and creative strategic learning; (2) metacognition is more effective when practised in small groups rather than as a whole-class instruction; (3) metacognition can be enhanced by using materials such as concept maps and annotated drawings to monitor one's conceptual development; and (4) metacognitive instruction can have a positive impact on the durability of one's conceptions and on one's ability to transfer new knowledge to other contexts. These

findings suggest that metacognition can be used as a teaching strategy to develop one's learning.

Problems associated with metacognition relate to its tacit nature. Metacognition is an inner awareness or process rather than an overt behaviour and is difficult to identify and measure (Georghiades, 2004). Georghiades acknowledges that this elusive nature of metacognition is due to the fact that most individuals are often not aware of the processes of metacognition in action. Metacognition, being an inner construct, relies heavily on the subjective judgement of researchers in trying to identify and measure it. Lack of reliable tools to record it and make it available to others makes one's metacognitive thoughts to be difficult to explicitly explain. Attempts to explain one's metacognitive thinking is restricted to observable features and what remains unsaid by one verbally remains unexplored (Georghiades, 2004).

This study embraces both the self-appraisal and self-management aspects of metacognition since the research took the form of a self-study. The study is aware of the controversy surrounding self-appraisal and self-management metacognition (Georghiades, 2004). The study has however chosen both forms of metacognition based on the critical element of judgement that these forms hold essential in ensuring that the process of learning is enhanced. Critical self-appraisal and management is an undertaking that requires the study to take an objective stance in identifying, acknowledging and reporting on errors, partial understandings or personal routes towards learning as suggested by Georghiades. Such undertakings make the study to be unbiased and trustworthy. Thus, metacognitive reflection is used in this study as a way of critically revisiting the thoughts or actions taken during the learning process (self-appraisal). Metacognitive monitoring is used as a reflective feedback meant to assist the study into taking informed decisions to rectify any learning challenges that are encountered during the learning process (self-management).

In chapter 3, I discuss the research design used in this study. The chapter explains in details the approach undertaken in the study, the participants in the study, the context of study, the research instruments as well as the processes of collecting data. The chapter will also elaborate on ethical issues necessary to be undertaken to ensure that the study is valid and trustworthy.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines a methodology that is adopted to conduct the study. Samaras and Freese (2006) refer to methodology as a set of practices, procedures and guidelines used by those who work or engage in an inquiry within a particular discipline. Methodology is philosophical, thinking work concerned with how the researcher goes about validating the evidence gathered, using appropriate research methods and instruments of collecting and analysing data (Opie, 2004). Opie further suggests that methodology also concerns ethical issues that should be addressed which might affect the participants involved in the study as well as the context in which the study will be conducted.

The study chose the methodology discussed herein in order to align the purpose of the study with the research questions and the theoretical framework used. The chapter describes the research methodology as an approach chosen for the study, the research methods adopted by the study, the research instruments used to collect and analyse data, the participants in the study, and the context in which the study is situated. Ethics issues are discussed with a purpose of ensuring that the study is credible and trustworthy. The chapter concludes by describing how data was collected and validated.

3.2 Research design

The research design chosen for this study is an autobiographical self-study of teaching. Samaras and Freese (2006) define self-study of teaching as a systematic inquiry-oriented approach undertaken by the self to explore one's practice. They argue that self-study of teaching is a systematic and critical examination of one's teaching beliefs and issues of concern embedded in ones' own teaching practice. Samaras and Freese maintain that this reflective inquiry contributes to the teacher's

growth and development as a person, a professional in his/her own practice as well as the advancement of educational reform.

According to Mooney (1957) in Bullough and Pinnegar (2001) "[self-study] research is a personal venture which, quite aside from its social benefits, is worth doing for its direct contribution to one's self-realisation" (p. 13). Bullough and Pinnegar maintain that self-realisation is not only about knowing who the person is, but also about what the person does to overcome the challenges he/she faces in life [or practice]. The challenges I encountered with regards to learning to teach the topic on *electromagnetism* made me realise my lack of knowledge regarding the teaching of this topic. This prompted me to engage in this study so as to discover ways to improve my teaching and to gain meaningful insights into issues that are of concern regarding the topic. By engaging in such a project, I hope that this study will assist me in better understanding myself as a person and as a teacher in the practice in which I am involved.

Bullough and Pinnegar (2001) warn that self-study research does not focus on the self per se but on the space between the self and the practice engaged in. They recommend that self-study only moves into research when a balance is struck amongst the self in relation to the practice, the context and those who participate in it. They further note that this balance can be struck many a times during the self-study process, but when the study is reported the balance should be in evidence of the data collected and analysed as well as how all these elements have been brought together in conversation. Thus, my decision to choose this approach over the others was based on the fact that self-study offered me better opportunities not only to understand myself as a person and as a teacher, but also to better understand my teaching, learners, the context and curriculum.

According to Samaras and Freese (2006), self-study research to a large extent, advocates the same practices and similar purposes just like action research. Both these researches involve a cyclic process which includes inquiry, reflection and action to collect and analyse data in order to improve the practice. According to Samaras and Freese, action research differs from self-study research in that it focuses more on what the teacher does (action) and not so much about who the teacher is (self). Other

distinctive features that make self-study different from action research and other researches are "openness, collaboration and reframing" (Samaras & Freese, 2006, p. 34). Self-study was chosen over other researches in that: (1) it will open my study to public scrutiny; (2) its collaborative nature will offer other participants the opportunity to voice their perspectives; and (3) its framing and reframing approach will assist me in looking differently at my challenges so as to change my practice.

Samaras and Freese (2006) maintain that self-study employs diverse qualitative research methods that depend on the purpose of the study. They further maintain that the use of diverse methods for uncovering evidence in accordance with the purpose of study is invoked by the research questions or concerns under consideration. Their argument is supported by Bullough and Pinnegar who argue that methods must not prescribe problems but rather problems must prescribe methods. Samaras and Freese argue that self-study approach utilises a variety of research methods such as observations, interviews, and artefact collections for collecting and analysing data while always maintaining a focus on the self. They further argue that the use of multiple research methods contributes to the uncovering of evidence that will ultimately lead to the credibility and validity of the study.

Bullough and Pinnegar (2001) identified two challenges facing self-study research with regards to its significance and quality. These challenges concern self-study's methodology and its virtuosity of scholarship (scholarly reporting). Bullough and Pinnegar argue that self-study methodological challenges stem from the fact that its methods of inquiry are borrowed and blended, and that its data tend to expand greatly such that it becomes difficult to represent, analyse and report. They also maintain that the challenges of virtuosity of scholarship involve the form in which the study is organised, methods are employed, and the skill with which an argument is made and a story is told. These challenges suggest that the researcher must be a methodologist and a skilful writer whose study is grounded in methodological traditions and appropriate forms of scholarly reporting.

To address the challenges of self-study methodology and its virtuosity of scholarship, Bullough and Pinnegar (2001) suggest that self-study should take a form of an autobiography. An autobiographical self-study is a narrative work of the researcher

who presents a set of ideas that participants deeply care about (Bullough & Pinnegar, 2001). Bullough and Pinnegar further suggest that for the reader to be interested and emotionally attracted to the conversation of a narrative, the researcher must ensure that the study adheres to the guidelines of autobiography. These guidelines include amongst others those that I seek to accomplish in this study.

In this study I: (1) articulate problems and issues that are central to my practice in an honest way; (2) improve the learning and teaching of this topic not only for me but for other colleagues who may find themselves in the same predicament; and (3) attend carefully to participants in context so as to offer fresh perspectives on the learning and teaching of the topic.

3.3 Participants

Samaras and Freese (2006) argue that participants play a crucial role in an autobiographic self-study process. Participants provide the researcher with alternative perspectives of viewing the issue under consideration. Through dialogue and interaction with others, the researcher is able to question his/her own views and those of others so that he/she can make informed decisions regarding his/her actions. By welcoming the views of others, the researcher is able to reflect beyond his/her own personal views and this strengthens the validity of the study.

The section that follows discusses the researcher and other participants who participated in the study. Their participation helped immensely in the development of my PCK.

3.3.1 The researcher

I am a qualified Physical Sciences and Mathematics teacher at a secondary school in Ekurhuleni in Gauteng, South Africa. My teaching career began in 1989 after I had obtained a three-year Secondary Teachers' Diploma from a teacher college. My teaching was confined to teaching grades 8 and 9 learners at a junior secondary school where I began teaching. However, I was afforded the opportunity to teach Physical Sciences to grades 10-12 learners after the school was turned into a fully-fledged

secondary school. My association with the school lasted until 1993 when I was offered a chance to teach grades 10-12 learners at another secondary school. I have been teaching in that same school since then.

The changes brought in by the new national curriculum in secondary schools around the country in 2000 and my lack of adequate knowledge of the new content and teaching strategies made me realise the need to improve my practice. In 2003, I enrolled as a part-time learner at the University of Johannesburg where I completed a Further Diploma in Science Education in 2004. I then went on to enrol with the University of Witwatersrand in 2006 where I obtained a Bachelor of Science Honours Degree in Science Education in 2007. It was during this period of my association with the university that I was introduced to the self-study of teaching. My desire to improve myself further as a person and as a professional encouraged me to pursue a Master's Degree in Science Education with the university.

My teaching philosophy is driven by the desire to better understand the curriculum and improve my teaching and my learners' learning. My belief is that one needs a strong knowledge base of the content and pedagogy in order to teach effectively and with confidence. According to Samaras and Freese (2006), effective teaching can be better achieved if the teacher is aware of the limitations and successes of his/her own practice. It is through such awareness that the teacher is able to problematise his/her own practice so he/she can critically examine his/her actions, those of his/her learners as well as any other issues that are of concern to his/her own practice (Samaras & Freese, 2006). Questioning one's beliefs, actions, ideas and those of the learners enables one to gain meaningful insights into one's practice and thus improve his/her own practice (Samaras & Freese, 2006). This approach to teaching helps me to better understand myself as a person and as a teacher, my learners as well as the context in which my practice is situated.

3.3.2 The learners

Only one class out of three classes that are taking Physical Sciences in grade 11 was chosen for the study. The reason for choosing this class was that this was the only class I taught at this level. The other two classes were taught by another teacher.

Although I would have loved to teach at least two classes so that one could make comparisons, this was not possible as doing so would disrupt the programme of the other teacher. I also thought that it would be better if I could teach one of the two classes taught by my colleague after school hours. However, after some deliberation with my colleague, we felt that this would not benefit the study as most of the learners in these two classes were never before exposed to my style of teaching.

Twenty three learners out of a class of 26 grade 11 Physical Sciences learners took part in the study. These learners took English as a second language and as a medium of instruction. Based on the previous interactions I have had with them, the majority of these learners were less competent in English such that their learning was partly being hindered by their poor proficiency in English. All the learners were African. There were 14 boys and 12 girls in the class. The three learners who did not take part were absent from school for various reasons when the study was conducted. The average age of this class was seventeen and conformed to the expected year of schooling in grade 11. Most of the learners came from poor families, some from broken-families and some were orphaned. The majority of these learners were however cooperative at school. Based on the assessment that was conducted before this study, the majority of these learners were performing below expectation.

3.3.3 Critical friend

Opie (2004) asserts that critical friends are of value to the study as their constructive and non-judgemental feedback ensures that the study is credible and trustworthy. Critical friends ensure that anything that is unclear, ambiguous, offensive, unsupported by evidence, or poorly presented is attended to before the study is implemented or presented (Opie, 2004). My supervisor served as a critical friend in this study. He was responsible for ensuring that my academic writing was clear, concise, critical, credible, evidenced, well structured and well presented as suggested by Opie (2004). His constructive input ensured amongst others that I used an appropriate system of citing and referencing, that the methods and instruments of collecting and analysing data were in line with my research questions and that my findings were supported by evidence. He was also responsible for ensuring that I develop the CoRe, concept maps and lesson plans as part of data collection.

3.4 The context

This study was conducted at a secondary school situated in a township on the eastern side of Ekurhuleni in Gauteng. The township is an informal settlement with a population of about 20 000 residents. The township has low-cost houses and shacks built from corrugated iron. Most parts of the settlement have running water and electricity. Most families fall in the low-income group as parents either get meagre salaries if employed or no salaries if unemployed. The settlement has a high crime-rate.

The school has a good infrastructure comprising 36 classrooms, two science laboratories, a consumer studies centre, two multi-purpose classrooms, a computer centre, and a school library. However, most of these rooms and centres have insufficient materials to cater for the number of learners enrolled in the school. The school has a staff of 51 teachers (1 principal, 2 deputy principals, 9 heads of departments, and 39 teachers), 4 administrators, 6 ground workers and 1535 learners.

One of the science laboratories was used to teach the grade 11 class for the entire duration of study. This was done for two reasons: (1) to ensure that unforeseen disruptions such as classroom organisation of the furniture and equipment are kept at a minimum, and (2) to give me ample time to prepare materials before the lessons commenced. An arrangement was made with other science teachers to use the other laboratory while the study was underway.

3.5 Research methods

The research methods chosen for the study are artefacts and classroom observation. The choice of these methods is consistent with this study since Samaras and Freese (2006) suggest that these methods are amongst those that are suitable for an autobiographical self-study. However, these methods were not only chosen for their appeal to this form of study but also because of the purpose of the study and the research questions set forth in this study. Using both these methods in collecting and

analysing data gave me alternative perspectives of addressing the research questions and hence the purpose of the study.

Samaras and Freese (2006) state that using multiple research methods assists in triangulating the data gathered in a study. Golafshani (2003) argues that triangulation refers to the use of various research methods so as to strengthen the validity and reliability of the study. In this study, artefact collection was used to probe the source documents so as to establish school policy related issues regarding the learning and teaching of the topic on *electromagnetism*. Classroom video recordings were used to probe my teaching so as to establish those aspects of teaching that needed development and deeper understanding.

3.5.1 Artefact collection

Hatch (2002) argues that artefact collection is part of many qualitative research projects. He, however, warns that it is unusual for artefacts to be used as the primary source of data except when they are text-based materials in archival, policy-based, or historical studies. According to Hatch, the main advantage of artefact collection is that it serves as indicators or non-reactive measures of a group or individual life and thus do not influence the social setting being studied. Its major limitation is that "interpreting the meaning and significance of objects is difficult because connecting them to relevant contexts is highly inferential" (Hatch, 2002, p. 25).

In this study, artefacts such as the national curriculum statement, content document and grades 10-12 textbooks (namely *Oxford Successful Physical Sciences, Focus on Physical Sciences, OBE for FET Physical Sciences, Study & Master Physical Sciences and Millennium Physical Sciences*) were used as the sources of data collection as these are school policy text-based materials. Tertiary textbooks such as *College Physics* and *Physics Principles with Applications* were also consulted with a view to expanding my knowledge of the topic. These text documents were used to capture the content that need to be studied, the learning and teaching strategies to be employed and instructional representations which were relevant for the topic. The use of the variety of these documents was done in order to minimise their inferential interpretive

nature with regards to the meaning and significance of objects and their connection to the context under study.

Other artefacts such as concept maps, CoRe and PaP-eRs, lesson plans, post-test, and reflective journal were drawn from these documents. These artefacts were meant to further probe the source documents so as to gain meaningful insights into them. Artefacts are defined as "the intended and unintended residues of human activity that give alternative insights into ways in which people perceive and fashion their lives" (Hatch, 2002, pp. 24-25). Breaking the data into small manageable parts helps in better understanding the bigger picture of what is happening within a situated context (Hitchcock & Hughes, 1995).

3.5.2 Classroom observations

Classroom observations were used to address the second research question: How does my PCK develop as I teach the topic on *electromagnetism*? In this study, classroom observations were conducted so that they could reveal those aspects of learning and teaching that would otherwise be difficult to explore with other research methods. These aspects of learning and teaching include: teacher and learner behaviours, learning environment, learning and teaching strategies, topic-specific representations, and the curriculum.

Opie (2004) argues that observation has the potential of providing greater insights into issues that have to do with actual practice in that it allows the researcher to observe what is actually happening rather than relying on perceptions of what is happening, which result from other research methods such as interviewing. Its aim is not just to assist the researcher to gain knowledge that informs his/her actions in a practice but also to produce public knowledge that will help others better understand the issue under discussion.

According to Opie (2004), classroom observations have an advantage over other research methods in that the researcher can directly record information about the physical environment and human behaviour. The data collected from this type of method can serve as a useful check or supplement to other data obtained by other

means (Opie, 2004). Its main limitations are that: (1) people tend to change their behaviour when observed and this may distort the naturalness of the setting, and (2) observation may be distorted by the observer interpretation.

3.6 Research instruments

This section discusses the instruments that were used to collect data. These instruments are concept maps, CoRe and PaP-eR, lesson plans, post-test, reflective journal, and audio and video recorders.

3.6.1 Reflective journal

The reflective journal was used to record the day-to-day events and other information regarding the study. It contained field notes taken during lesson presentations, discussions and conversations I had with the learners, references of articles and textbooks I read and their relevant input, as well as my frustrations and successes regarding my engagement with the study. The reflective journal was kept throughout the study.

Kerka (1996) defines a reflective journal as a learning tool used to systematically document and collect information for self-analysis. Hatch (2002) recommends that researchers should keep journals so that they could keep track of their impressions, reactions, reflections, and tentative interpretations as the study unfolds. Opie (2004) suggests that one advantage of keeping a journal is that "as the research progresses, and theoretical ideas begin to develop, focus on particular aspects of behaviour or situations can be made" (p. 124). However, he warns that since it is impossible to record everything, care should be taken as some of the valuable information may be lost along the way.

3.6.2 Concept maps

Three concept maps (Appendix A) were constructed at three different stages of my learning. The first concept map was constructed after I had consulted the Physical Sciences content document to establish the content that needed to be covered in the

topic on *electromagnetism*. The second concept map was constructed just before I presented the topic after I had consulted various textbooks and literature articles on the topic. The third concept map was constructed after I had finished presenting the topic to the learners. The construction of these concept maps was meant to monitor the progress of my learning and to identify gaps in my learning so that appropriate actions would be taken to improve my learning.

Adamczyk and Willson (1996) define a concept map as an active learning tool used to identify gaps in knowledge and misunderstandings to be targeted and rectified through a series of planned activities. Samaras and Freese (2006) view concept maps as artistic and cognitive tools that allow one to discover and demonstrate conceptual connections between and within concepts. A concept map consists of key concepts interlinked by propositional statements and direction arrow lines. According to Samaras and Freese, these concepts should be ideas derived from conscious perception and classification of facts and events based on their common characteristics.

3.6.3 CoRe and PaP-eR

In this study, the CoRe (Appendix G) and PaP-eR were used to capture, document and portray the development of my PCK regarding the topic on EMI. The CoRe allowed me to transform the content into knowledge accessible for teaching. Four big ideas were established regarding the learning and teaching of EMI. Each big idea was probed using the prompts in the CoRe to establish specific information about its learning and teaching that needed to be addressed before teaching the topic. The PaP-eR gave a narrative account of how I intended to give insight into those aspects of my learning and teaching that needed to illuminate my PCK.

Loughran *et al.* (2004) developed a Resource Folio format that captures important aspects of teacher's knowledge of the content and pedagogy. This format is made up of two elements called the CoRe and PaP-eRs. According to them, a CoRe is an overview of the content taught when teaching a particular topic whereas PaP-eRs are specific accounts of practice that are intended to offer windows into aspects of the CoRe. A CoRe consists of horizontal rows in which the key ideas of the topic (called

'big ideas') are listed. The vertical columns of the CoRe consist of prompts which probe each big idea so that specific information about its learning and teaching can be made explicit. A CoRe is thus a generalisable form of the teacher's PCK as it links the content to be taught to what shapes learners' learning and teacher's teaching (Loughran *et al.*, 2004).

Loughran *et al.* (2004) warn that a CoRe is not a teacher's PCK in itself in that the information it contains tends to be propositional in nature and is thus limited in providing insights in teacher's experiences of practice. They recommend the development of PaP-eRs which are drawn from the CoRe itself as valuable instruments to capture teacher's PCK. A PaP-eR is a narrative account of a teacher's PCK that highlights a particular aspect of content to be taught (Loughran *et al.*, 2004). According to Loughran *et al.*, PaP-eRs are designed to purposefully unpack teacher's thinking and actions about a particular aspect of PCK in a given topic and so are largely based around classroom practice. Thus, PaP-eRs bring the CoRe to life and offer one way of capturing the holistic nature and complexity of PCK (Loughran *et al.*, 2004).

3.6.4 Audio and video recorders

Audio (MP3 players) and video recorders were used mainly to capture the events that took place during instruction. A former learner who is a part-time photographer assisted me with the technical issues regarding the workings and use of these instruments. The video recorder was used to capture four of the six lessons that I presented on EMI. One audio recorder was suspended around my neck during instructions and the other five were placed on the work-stations to capture learners' conversations during practical activity sessions that took place in the classroom.

Opie (2004) recommends audio- and video-recordings as other ways of collecting data for analysis in natural settings. When properly implemented, audio-recorders preserve the natural language of the participants in a setting whereas video-recorders enable the researcher to record directly information about the physical environment and human behaviour of the participants. Data colleted from these instruments can be used later for re-analysis and/or as a check against bias or misinterpretation (Opie, 2004).

However, Opie (2004) warns researchers about the problems these instruments bring with them when not used properly. He suggests that researchers must ensure that these instruments are in good condition before they are used and that researchers should have the technical ability to use them. He also warns the researchers to consider the ethical issues which these instruments bring with them and to ensure that these issues are adhered to at all times as failing to do so may affect the behaviour of the participants. The use of these instruments also means that the researchers must have sufficient time to transcribe them for analysis purposes as transcription of them require more time.

3.6.5 Lesson plans

Six lesson plans were designed for the purpose of sequencing and facilitating the teaching of the topic on EMI. The first lesson focused on the introduction of the EMI concept. The next lessons focused on concepts such as induced current, magnetic flux, induced emf, mutual induction and transformers respectively. However, only the first four of the lesson plans are attached in appendix H as the last two lessons (i.e. mutual induction and transformers) do not form part of this study.

The Department of Education (2006) expects each teacher to design lesson plans for each topic they teach. Each lesson plan should indicate the content, context, learning outcomes and assessment standards drawn from the work schedule. Teachers are expected to develop learner and teacher activities, select suitable teaching methods, choose appropriate learning and teaching support materials, and assessment strategies that will facilitate learning and teaching.

3.6.6 Post test

A test (Appendix J) was designed according to the standards set by the School Based Assessment Guideline document for Physical Sciences (Gauteng Department of Education, 2009). It indicated all the learning outcomes and assessment standards that were assessed by the test as well as all the other information that is required to be indicated on the question paper. The test questions were sequenced as stipulated by

the Examination Guideline for Physical Sciences (DoE, 2009). The test consisted of one word answer questions, false items questions, multiple choice questions and long questions assessing the different sections covered under this topic. The test was administered a week after I had completed teaching the topic.

The purpose of the test was not just to measure learner performance, but also to serve as a means that will lead me to some form of intervention or remedial action. The test was meant to establish learners' strengths and weaknesses regarding the topic as well as the misconceptions they still held after they had completed the topic. Its administration was also meant to assist me in reviewing the teaching strategies and instructional representations that I had used during the teaching of the topic. Thus, the test also served as a way of reflecting on my development regarding the learning and teaching of the topic.

3.7 Data collection

Data was collected over a period of six months in the last semester of 2009. Data collection commenced when I constructed my first concept map (Appendix A). This occurred while I was reviewing the NCS Grades 10-12 (General) Physical Sciences and NCS Physical Sciences Content documents, trying to establish the structure and depth of the content on EMI. During this period, it dawn on me that this was the right opportunity to construct my first concept map since I had just learned what this topic entails. Thus, my first concept map was drawn based on the knowledge that I had acquired primarily from the content documents. This concept map had four concepts which were linked to the EMI concept.

The second stage of data collection occurred when I was reviewing journal articles, grades 10-12 school textbooks and first-year tertiary textbooks on *electromagnetism*. Grade 10 textbooks were consulted with a purpose of establishing knowledge that my learners were likely to bring to class regarding the topic. Grade 11 textbooks were consulted with a view to establishing the content learned in this grade, appropriate learning and teaching strategies, topic-specific representations as well as topic sequencing. Grade 12 textbooks and tertiary textbooks were reviewed with two purposes in mind: (1) to establish ways in which I could teach the topic in such a way

that it linked with higher learning, and (2) to acquire a deeper understanding of the topic itself. Journal articles on *electromagnetism* were consulted with an intention to establish the topic's learning and teaching strategies, its preconceptions and topic-specific representations.

It was during this period of learning that I developed a CoRe on EMI. This CoRe consisted of four big ideas of which each was explored using the prompts listed on the left vertical column of the CoRe. These prompts focused on the aspects of the content that pertains to its learning and teaching such as the reasons why learners should learn these ideas, the extent to which learners should know about these ideas, difficulties associated with the teaching of these ideas, factors that influence the teaching of these ideas, teaching procedures and ways of ascertaining learners' understanding. Thus, the CoRe was developed from the knowledge that I had acquired from reading the journal articles, various textbooks as well as the NCS documents. The construction of the CoRe assisted me in shaping the topic the way I wanted my learners to learn and understand it without deviating from the curriculum.

The third stage of data collection took place when I drew my second concept map just before teaching the topic. This concept map was drawn based on the knowledge that I had acquired from the first concept map, various textbooks and the NCS content documents. The second concept map had grown in structure considering the number of concepts, its complexity and connectedness it had compared to the first concept map. The second concept map and the CoRe were used to design the six lesson plans that were used to present the lessons. Each lesson plan indicated all the activities that needed to be covered during each lesson, outlined the actions that needed to be taken by both the teacher and learners, and listed the key points that were the focus of each activity as well as the learning and teaching support materials that were required to be used to attain the learning outcomes.

The fourth stage of data collection took place when these lessons were presented to the learners at school. A video recorder was used to record four of the six lessons that I presented on EMI. The former learner assisted in video-recording the lessons. The video recorder was placed at a strategic position on a tripod stand in front of the classroom so that those learners who did not wish to be captured were not videotaped.

The photographer was however able to move around during the lesson presentations when learners were doing group activities to capture what was happening in the groups. An audio recorder which was suspended around my neck was used as a backup to the video recorder to capture verbal conversations that took place during the lessons. The other audio recorders were used only when learners were involved in group-work sessions. Field notes were recorded on the reflective journal after each lesson presentation.

A number of problems were encountered during video recording of the lessons. Three of the learners who had initially agreed to be part of these lessons decided that they were no longer willing to be part of these sessions and were excused from taking part. Three other learners did not take part in all the sessions that were presented due to their irregular attendance. However, their absenteeism did not affect the smooth running of these sessions as the majority of the learners were excited to be part of these lessons. The sessions went on as planned except that some were disrupted by noise from the learners who were changing classes at the end of the periods. Three of the five learners who had initially asked not to be videotaped later wanted to be captured on video. They were allowed to join the other learners after they had sought permission from their parents.

The fifth stage of data collection involved the administering of the test one week after the six lesson presentations were completed. Learners were given a week to prepare as there were other subjects that they were studying besides Physical Sciences. They were informed of the structure that the test would take and that they should revisit the activity tasks that they did during the lesson presentations as the test would focus more on those questions that were in those tasks. Twenty learners took part in the test that lasted one hour thirty minutes. The other three learners wrote the test later as they had reported sick on the day the test was written. Their results were however not considered for analysis.

The final stage of data collection involved the construction of the third concept map and the writing of a PaP-eR based on the salient features of the topic. The concept map was drawn after I had completed marking the test scripts. This concept map was more complex in structure than the first two concept maps as it included other aspects

of my learning and teaching which I had gathered during the presentation of the lessons. The PaP-eR that was chosen for the purpose of the study focused on the sections of the topic which I considered illuminated the development of my PCK. This PaP-eR is discussed in details in chapter 5 of the study.

Bell and Opie (2002) in Opie (2004) suggest that neither time nor access is usually available for large amounts of data to be collected and even if these were available then the overall timescale for a master's research will almost invariably limit the analysis of such data. Thus, this study used concept maps, the CoRe and PaP-eR, and video recordings of the lessons as the primary sources of data and analysis to limit the scope of the study. The reflective journal, lesson plans, audio recorder and post-test were used as secondary sources of data to supplement the primary sources. Their inclusion in the list of research instruments discussed above was meant to make the reader aware of the other instruments that were used to collect data, and that these instruments were used whenever the study called for them.

3.8 Ethical considerations

Sieber (1993) in Opie (2004) argues that "ethics has to do with the application of moral principles to prevent harming or wronging others" (p. 25). Ethical considerations ensure that the identity and dignity of those involved in the study is protected and respected and that no one is harmed as a result of the activities of the study. Sieber goes on to say that organisations and institutions have their own codes of conduct that need to be observed and respected. Thus, a study should at all times show awareness of the rights of participants, organisations and institutions involved in the research.

An application form was submitted to the Human Research Ethics Committee (HREC) of the University of the Witwatersrand seeking permission to conduct this research. This form was accompanied by the research proposal document which indicated how the research would be conducted. The Gauteng Department of Education (GDE) Research Request Form was also completed and submitted to the GDE offices requesting permission to conduct the study in one of its schools. This

request was done after the university had granted me permission to proceed with the study.

Letters of approval from HREC (Appendix K) and GDE (Appendix L) as well as letters to the principal (Appendix M) and parents (Appendix N) were sent to the school where the study was conducted. Attached to the letter to the parents was a consent form requesting them to indicate whether or not they approved that their children should take part in the study. The purpose of the study and how the study would be conducted were explained in letters that were sent to the principal and parents. In these letters I indicated that participation in the study was voluntary and that learners were free to withdraw from the study at anytime they wished to do so. It was also explained that alternative arrangements would be made for those learners who did not wish to be part of this study for them to be taught this topic at their convenient time as this topic was part of the curriculum.

Learners who wished to be part of this study but did not wish to be captured in the audio and/or video recorders were assured that their identity would be kept confidential. This was done by placing them at strategic places in the classroom such that they were not captured in the video. Furthermore, their names were erased from the audiotapes and videotapes. The school and the parents were assured that pseudonyms would be used to protect the identity of the participants unless otherwise permission to use real names was granted. The school and the parents were also assured that the data collected during the study would be destroyed by fire after the study had been completed and that should any institution(s) wish to use this data for other educational purposes, the school and the parents of learners would be consulted for approval.

Opie (2004) emphasises that it is essential for the writer to acknowledge the work of others that has been used in one's work. Doing so is a sign of "strength and part of the process of outlining your positionality or the inevitable agendas that you bring to your writing as a result of your beliefs, values and experiences" (Opie, 2004, p. 40). Thus, in this study, quotes and extracts that were borrowed from other texts were cited and referenced in the reference list provided in the research report.

3.9 Validity

Traditionally and technically validity refers to the degree to which a study accurately reflects or assesses the specific topic that the research is attempting to measure (Feldman, 2003). Feldman argues that validity ensures that the study is well grounded, just and can provide the desired results. The validity concept in qualitative research poses some problems as this concept is associated with accuracy which tends to focus more on quantifiable measurements. According to Feldman, accuracy in auto-biographical self-studies is limited by the researcher's subjective view, recall and experience and these in turn raises the questions of trustworthiness. To address the issues of trustworthiness, Feldman suggests four guidelines that can increase the validity of self-study research.

Feldman (2003) proposes that one way to increase the validity of a self-study is to provide a clear and detailed description of how data was collected and to make explicit what counts as data in the study. In this study, a detailed description was made under the data collection section above of how data was collected using various data sources. The study also made it clear that instruments such as concept maps, CoRe and a PaP-eR, and video-recorded lessons would count as the primary sources of data. Mention was also made that secondary instruments would serve to supplement the primary instruments when required. Details of these artefacts are provided within the study and in the appendices of the research report.

The second way to increase the validity of a self-study is to provide clear and detailed descriptions of the representations that were constructed from the data. Primary sources of data were constructed by using various source documents as mentioned in the data collection section above. A clear and detailed description of concept maps, CoRe and PaP-eR, and recorded lessons was done in chapters 4, 5 and 6 respectively. One of the reasons for selecting a chapter for each instrument was to provide the reader with detailed knowledge or insight into how I transformed data into artistic representations.

The third way of increasing the validity of self-study research involves triangulation. Feldman (2003) suggests that triangulation should extend beyond multiple sources of

data to include explorations of multiple ways to represent the same self-study. In this study, triangulation was explored in various ways. Firstly, two research methods were used namely, artefact collections and classroom observations to answer the research questions set forth in the study. Secondly, multiple instruments were used to collect as much data as possible and to ensure that some of the data missed by some instruments could be captured by the others. Thirdly, various ways of analysing data were employed to ensure that I extract concrete evidence that would support the findings of the study.

The fourth way of increasing the validity of the study is to provide evidence of the value of the changes self-study brings to the education community (Feldman, 2003). This self-study was instrumental in the growth and development of me as a person, a teacher and my practice. Evidence of this is provided in the last chapter of the study where the research questions are answered to confirm the development of my CK and PCK regarding the topic on *electromagnetism*. The last chapter also provides some recommendations and directions for future research. Such evidence can only be provided by opening the study to public critique so that others can have their input for the benefit of the education community.

Thus, data validation was done to ensure that the study answers the questions under consideration in a transparent, compelling way. Multiple avenues of exploring data using various research methods and instruments was done to ensure that the study captures, compares and provides evidence that supports its findings. By triangulating the research methods and instruments the study was attempting to critically reflect its findings rather than being self-congratulatory so as to strengthen its trustworthiness. Samaras and Freese (2006) suggest that data triangulation and opening the study for public critique contribute to the validity of the study.

3.10 Conclusion

This study chose an autobiographical self-study design. Artefact collections and classroom observations were used as the research methods to pursue the development and growth of my PCK. Research instruments such as concepts maps, CoRe and PaP-eR, and video-recorded lessons were used as primary sources of data and others as

secondary instruments. The participants in the study were the supervisor, researcher, learners, and the school in which the study was conducted. Ethics issues concerned with the participants involved in the study and issues concerned with how the data was collected and validated were discussed. Chapter 4 will focus on how the concept maps were constructed and analysed.

CHAPTER 4

ANALYSIS OF CONCEPT MAPS

4.1 Introduction

This chapter first discusses how the three concept maps were constructed during data collection. This is followed by the analytical framework which consists of two methods of analysing the concept maps. Each method of analysis is discussed separately showing how the data was processed and analysed. The results are then discussed followed by a conclusion for each method of analysis. The chapter ends with the overall conclusion of the three concept maps.

4.2 Construction of the concept maps

Kinchin, Hay and Adams (2000) recommend three ways in which concept maps could be structured. These are spoke, chain and net structures. Kinchin *et al.* define a spoke concept map as a radial structure in which all the related aspects of the topic are linked directly to the core concept but these aspects are not directly linked to each other. Kinchin *et al.* describe a chain concept map as consisting of a linear sequence of concepts in which each concept is only linked to those immediately above and below it. They view a net concept map as a highly and hierarchical network demonstrating a deep understanding of the topic.

Each concept map that I constructed consisted of words or phrases enclosed in boxes. These words or phrases represent concepts or ideas about the concepts. The boxes were connected by lines with directional arrows which represented links or relationships between the concepts. Each link was accompanied by linking words or phrases which together with the concepts or ideas about these concepts formed a complete thought called a proposition. The concept maps were constructed in such a way that concepts closely related to the core concept were closely linked directly to the core concept. Concepts not so closely related to the core concept were connected further away resulting in a hierarchical network.

All three concept maps that I constructed took the form of a net structure. The net structure was chosen over the other structures based on its ability to accommodate the addition of other concepts at various levels of the concept map without disrupting the knowledge structure I was gathering. Kinchin *et al.* (2000), suggest that a hierarchical network structure offers a number of routes to access a particular concept and that this makes knowledge more flexible. The spoke structure was not suitable because it offered one way to access the concepts that are associated with the core concept, and that was through the core concept itself. The chain structure was also not suitable because the addition of the concepts become more difficult if a workable sequence is already in place (Kinchin *et al.*, 2000).

The construction of concept maps was meant to show what knowledge I hold and to illustrate how this knowledge is arranged in my mind. The construction of concept maps at different times of my learning was meant to monitor my progress of learning the topic on electromagnetic induction (EMI). The concept maps were meant to assist me in identifying those aspects of learning that required development so that I can take action in improving them. Kinchin *et al.* (2000) argue that concept maps are useful in revealing thought processes that generally remain private to the mapper. Thus, the generation of these concept maps was an attempt to probe my understanding of the topic and to make it explicit to the reader in a documented form.

4.3 Analytical framework

This study used two methods of analysing concept maps identified by Hough, O'Rode, Terman and Weissglass (2007). These analytical methods are structural analysis and content analysis. Structural analysis involves the scoring of the structural components of the concept map using six variables identified by Hough *et al.* Content analysis explores how the content in the mind of the mapper evolved while constructing the concept maps during the entire period of learning. The two-prong approach was chosen with a purpose of triangulating the information gathered from these methods so that I could validate the findings that emerged from them. These methods are discussed separately in the sections that follow.

4.4 Structural analysis of the three concept maps

Hough *et al.* (2007) suggest six variables to analyse the structure of the concept map. These variables are concept number, width number, depth number, hierarchical structure score (HSS), chunk number and crosslink number. A concept number represents the total number of concepts on the concept map. The width number represents the greatest number of concepts at one particular level of the concept map. The depth number represents the length of the longest chain on the concept map. The HSS refers to the sum of the width and depth scores. The chunk number represents the total number of chunks on the concept map whereas the crosslink number represents the total number of crosslinks on each concept map.

These six variables for scoring concept maps as identified by Hough *et al.* (2007) can be classified into three categories as shown in Table 4.1 below. These categories are conceptual acquisition, complexity and connectedness. Conceptual acquisition, which is determined by the total number of concepts in each concept map, assesses the amount of concepts that a mapper has acquired at a particular stage of learning. The hierarchical structure score, which is obtained by adding the width and depth scores, assesses the complexity of the structure of the concept map. The chunk number and the crosslink number represent the connectedness of the concept map structure. Connectedness assesses the extent to which concepts and thoughts are interconnected, demonstrating deeper understanding of how topics are interrelated (Hough *et al.*, 2007).

Table 4.1: Categories showing how the six variables have been classified

Categories	Variables	Variable Function
1. Conceptual acquisition	Concept number	Assesses the amount of terms the mapper has acquired at a particular stage of learning
2. Complexity	Width number	Assesses the breadth of knowledge the mapper has acquired.
	Depth number	Assesses the depth of knowledge the mapper has acquired.
	HSS	Assesses the complexity of the map structure.
3. Connectedness	Chunk number	Assesses the extent the mapper groups and orders concepts
	Crosslink number	Assesses the extent to which the mapper connects concepts and thoughts

4.4.1 Coding system

A coding system was devised for the purpose of this study to capture and categorise the data to be analysed for each concept map. Highlighters of different colours were used to distinguish the different levels on each concept map, non-scientific concepts, chunks, crosslinks, and links left out because they were connected to non-scientific concepts. The indicators which were used to label some of the items found on the concept maps were derived in order to make these items easily identifiable. These indicators were represented by capital letters and numbers. Table 4.2 shows the coding system that was used to identify the different elements of the concept maps.

Table 4.2: Coding system used in the analysis of concept map

Level Codings	Level 1	Level 2	Level 3	Level 4	Level 5
Colour	yellow	pink	green	blue	orange

Item	**Colour**	**Indicator**
Non-scientific concept	brown	NSC + number
Chunk	-	C + number
Crosslink	red (line)	CL + number
Link left out	dark blue (line)	-

NOTE: NSC: Non-scientific Concept; C: Chunk; CL: Crosslink

The three concept maps were coded by me using the coding system shown in Table 4.2. All concepts that appeared in the same level in each concept map were assigned the same colour using highlighters. For example, concepts that appear in the first level of each concept map were highlighted with a yellow colour and those in the second level with a pink colour and so on. Coding the concept maps in this way enabled me to easily determine the number of concepts in each level of each concept map. The number of concepts in each level of the concept map was then added to give the total number of concepts for each concept map.

During coding, it became clear that some of the concepts in the three concept maps could not be regarded as scientific concepts. Some of these concepts are ‘solve problems’, ‘words and pictures to demonstrate’, ‘artefacts’, and ‘not for Gr 11’. These concepts are either related to the teaching strategies or subject matter representations that I intended to use in my lesson instructions. These concepts were retained in the

concept maps but marked as non-scientific concepts (NSC) using a brown highlighter. The decision to retain such concepts on the concept maps was based on the fact that these concept maps were constructed for both learning and teaching purposes. However, these concepts were not considered when evaluating my conceptual development of the topic.

Leaving out the non-scientific concepts meant that links connecting them to adjacent concepts should also be left out. These links were marked with dark blue lines indicating that they have been left out and that they would not be considered as part of the chunks they belonged to for the purpose of analysing conceptual acquisition. The chunks that were identified were marked using capital letter C followed by a number, for example C1 to depict chunk number one. The crosslinks that were identified were marked with a red highlighter along the crosslink and marked using capital letters CL followed by a number, for example CL1 to depict crosslink number one.

4.4.2 Data analysis

Each concept map (see Appendix A) was analysed using the six variables mentioned in Table 4.1, i.e. concept number, width number, depth number, HSS, chunk number and crosslink number. A summary sheet (see Appendix B) was completed at the back of each concept map showing how each variable was scored. Table 4.3 below shows the summary of the number of concepts in each level of the concept maps as well as the total number of scientific concepts for each concept map. The total number of concepts in each concept map was found by adding the number of concepts in each level of the concept map. The total number of concepts for the first concept map (CM1), the second concept map (CM2) and the third concept map (CM3) was found to be 15, 31 and 53 respectively (see Table 4.3).

Table 4.3: Total number of scientific concepts in each concept map

		Number of scientific concepts		
Level	**Colour**	**CM1**	**CM2**	**CM3**
1	yellow	4	6	8
2	pink	9	18	24
3	green	2	5	14
4	blue	-	2	6
5	orange	-	-	1
Total number		15	31	53

NOTE: CM: Concept Map

Table 4.3 enabled me to determine the six structural variables for each concept map which are summarised in Table 4.4 below. The width numbers for each concept map were found by looking for a level with the highest number of concepts in the concept map. Level 2 of each concept map consisted of the highest number of concepts. These are 9, 18 and 24 for CM1, CM2 and CM3 respectively. The depth numbers, which represent the longest chain in each concept map, were found by considering the number of levels in each concept map. Thus, the depth numbers were found to be 3, 4 and 5 for CM1, CM2 and CM3 respectively. The HSS for each concept map was determined by adding the width number and depth number. The HSS for the concept maps were found to be 12, 22 and 29 for CM1, CM2 and CM3 respectively.

The chunk number for each concept map was determined by counting the chunks found in that concept map. The chunk numbers for CM1, CM2 and CM3 were found to be 5, 8 and 14 respectively. For example, CM1 consisted of five chunks of which their leading concepts were Faraday's law, magnetic flux, induced current, right-hand rule, and changing magnetic field. Each chunk had two or more concepts connected to the leading concept as defined by Hough *et al.* (2007). Crosslinks were determined by looking for links that connected the chunks that were identified. The crosslink numbers for the concept maps were found to be 8, 11 and 15 respectively.

Table 4.4: Summary of the six structural variables for each concept map

Concept Map	Number of concepts	Width number	Depth number	HSS	Number of chunks	Number of crosslinks
CM1	15	9	3	12	5	8
CM2	31	18	4	22	8	11
CM3	53	24	5	29	14	15

Table 4.4 was used to compare the six variables of the three concept maps in order to determine the three categories that were chosen to analyse my conceptual development of the topic on EMI. These categories are conceptual acquisition, complexity and connectedness. Table 4.5 below shows a comparison of the three concept maps in terms of these three categories. Conceptual acquisition for each concept map was determined by the total number of concepts in that concept map. The complexity of each concept map was determined by the HSS which was calculated by adding together the width number and the depth number. The connectedness of each concept map was determined by adding together the chunk number and the crosslink number of that concept map.

Table 4.5: Comparison of the three concept maps in terms of conceptual acquisition, complexity and connectedness

Concept Map	Conceptual acquisition	Complexity	Connectedness
CM1	15	12	13
CM2	31	22	19
CM3	53	29	29

4.4.3 Results of structural analysis

The results of structural analysis are discussed below in terms of conceptual acquisition, complexity and connectedness of the three concept maps.

Conceptual acquisition

The results in column two of Table 4.5 show the total number of concepts that were acquired in each of the three concept maps as 15, 31 and 53 respectively. Each subsequent concept map retained all the concepts that were in the previous concept map. This happened because each subsequent concept map was constructed based on the knowledge that was gathered in the previous concept map and the new knowledge gained from the sources that were learned at the time of constructing the concept map. Retaining concepts that were in the previous concept map was essential (especially if they were scientifically correct) because losing some would mean deviation from the curriculum as CM1 was drawn primarily from the prescribed content documents.

The results show an increase of 16 concepts from CM1 to CM2 and an increase of 22 concepts from CM2 to CM3. This indicates that the number of concepts in CM2 is more than double that in CM1 and that the number of concepts in CM3 is more than triple that in CM1. The increase in the number of concepts from CM1 to CM2 shows that the new concepts contributed 51,6% (16/31 x 100) of the total number of concepts in CM2. The increase in the number of concepts in CM3 shows that the new concepts contributed 41,5% (22/53 x 100) of the total number of concepts. This decline in percentage only indicates that the new concepts contributed less than the number of concepts that were contributed by the first two concept maps.

The results also show that 38 concepts were learned after CM1 was constructed. This represents an overall percentage increase of 71,7% (38/53 x 100) of the number of concepts that were learned after CM1. Conceptual contribution in CM2 and CM3 can be attributed to three factors. The new concepts were contributing either to the development of the already existing knowledge structures, the reorganisation of the already existing knowledge structures that I had developed or the development of new knowledge structures that I had acquired while constructing CM1. For example, the knowledge structure on Faraday's law that already existed in CM1 grew in such a way that its supporting concepts such as the induced emf, rate of change of magnetic flux and the Faraday's law equation became knowledge structures themselves by the time CM3 was constructed.

The overall results show that CM1 contributed 28,3% (15/53 x 100), CM2 contributed 30,2% (16/53 x 100) and CM3 contributed 41,5% (22/53 x 100) of the total number of concepts that were learned during the entire study. These results suggest that more learning took place towards the final stages than in the early stages of concept map construction. This is understandable considering the fact that towards the final stages of learning I had acquired more knowledge of the topic regarding its structure and composition. This knowledge was acquired from the various text documents, the participants (critical friends and learners) that I collaborated with and the learners' assessment tasks with which I had interacted. CM3 was constructed after I had developed a deep understanding of the topic and this contributed to a more coherent knowledge structure regarding the topic.

Complexity

The results in column three of Table 4.5 represent the complexity of the structure of the three concept maps. The complexity of the concept map structures were determined by the hierarchical structure scores of the three concept maps. Table 4.4 represents how the width numbers and the depth numbers were summed up to give the HSS for each concept map. The section that follows discusses how each of these variables eventually contributed to the complexity of these concept maps.

Depth numbers

Table 4.6 below shows a summary of the concepts that resulted in the formation of the longest chains in each of the concept maps. The depth numbers of the three concept maps are also indicated in Table 4.6. The Table reveals that the depth numbers differed by one each time a subsequent concept map was constructed. This suggests that each subsequent concept map grew by one level from the previous concept map. The Table also reveals the leading concepts and their associated concepts that resulted in the formation of the longest chains in each concept map.

Table 4.6: The depth numbers of the three concept maps and their related concepts

Concept Map	Depth number	Leading concept	Associated concepts
CM1	3	Faraday's law	Induced emf; $\Delta\varphi/\Delta t$.
		Induced current	R-H rule; R-H rule definition.
CM2	4	Magnetic flux	$\Phi = BA$; magnetic field strength; magnetic field strength definition.
		Induced emf	Negative sign; $\varepsilon = -N\Delta\varphi/\Delta t$; N is no. of turns in coil.
CM3	5	Induced emf	N is no. of turns in coil; $\varepsilon = -N\Delta\varphi/\Delta t$; negative sign; direction of ε opposes that of φ.

The depth number of CM1 was as a result of two chunks with the leading concepts 'Faraday's law' and 'induced current'. The depth number of CM2 was as a result of two chunks with leading concepts 'magnetic flux' and 'induced emf'. The emergence of two new chunks with the longest chains in CM2 suggests that my depth of knowledge was increasing not only in the chunks that had the longest chain in CM1 but also in other chunks that already existed.

The depth number of CM3 was as a result of one chunk with a leading concept 'induced emf'. The induced emf concept started as an associate concept of the chunk with the leading concept 'Faraday's law' in CM1 and developed to a leading concept of one of the longest chains in CM2. This concept eventually became the leading concept of the longest chain in CM3. The evolving of the induced emf chunk into the longest chain in CM3 suggests that this chain developed more than the other chunks that were already in the concept map. This means that my depth of knowledge increased more on the induced emf chunk than on any other chunk in CM3.

The disappearance of the previous longest chains in subsequent concept maps does not mean that these chains ceased to exist or became less important in the depth of knowledge I was acquiring. They continued to contribute to the depth of knowledge I was acquiring in other ways than getting longer. For example, the magnetic flux chunk which had a depth number of four in CM2 continued to develop in that some of its associated concepts such as the magnetic flux equation ($\varphi = BA$) and magnetic field strength developed into other chunks in CM3.

Width numbers

The width numbers for CM1, CM2 and CM3 are 9, 18 and 24 respectively. These numbers suggest that CM3 had the greatest number of concepts at a particular level and that CM1 had the least number of concepts at a particular level. This means that my breadth of knowledge was larger in CM3 than in the previous concept maps. The width numbers also suggest that my breadth of knowledge doubled in CM2 and almost tripled in CM3 compared to CM1. The difference in width numbers between CM1 and CM2 is 9 and between CM2 and CM3 is 6. These differences suggest that my breadth of knowledge increased more in CM2 than in CM3.

A closer inspection of the concepts that contributed to the width numbers of the three concept maps reveals certain dimensions that the concept map structures took as the study progressed. The results show that 7 of the 9 concepts that were initially in CM1 were retained in the levels that contributed to the width numbers of the subsequent concept maps and that 9 of the 11 new concepts in the level that contributed to the width number of CM2 were retained in CM3. This suggests that: (1) the 7 concepts in

the level with the greatest number of concepts in CM1 were consistent in the development of the breadth of knowledge I acquired, (2) the 16 concepts that were previously in the levels with the greatest number of concepts in CM1 and CM2 contributed to the width number of CM3, and (3) 8 new concepts contributed to the increase in the width number of CM3 (as opposed to the difference of 6 between the width numbers of CM2 and CM3).

The four concepts that were consequently not retained in the level that contributed to the width number of CM3 are the 'induced emf' and 'ε = -NΔφ/Δt' from CM1 and 'microphones, seismographs and card swiping machines' and 'negative sign' from CM2. These concepts were not lost in the subsequent concept maps but went to occupy other levels in these concept maps. The 'induced emf' concept occupied the first level of the subsequent concept maps while the other concepts occupied lower levels. The 'ε = -NΔφ/Δt' concept even went to become a leading concept in a chunk lower in CM3 suggesting that it was growing in its own right.

Hough *et al.* (2007) suggest that concepts that are closely linked to the main concept are most related to the core concept. The fact that the levels with the greatest number of concepts in each concept map occurred in level 2 suggests that quite a number of concepts in each concept map were closely related to the topic. This suggests that my breadth of knowledge was indeed growing because had these occurred in lower levels this would mean that my breadth of knowledge was not growing enough. Some of these concepts such as 'magnetic field strength', 'φ = BA' equation, 'R-H rule', 'Δφ/Δt' and 'Lenz's law' which were in level 2 even developed into chunks in their own right in CM3.

The HSS and complexity

The HSS for CM1, CM2 and CM3 are 12, 22 and 29 respectively. These scores show that the complexity of the concept map structures grew from CM1 to CM3 and that CM3 was more complex than the preceding concept maps. The difference in HSS is 10 from CM1 to CM2 and 7 from CM2 to CM3. Although CM3 is more complex than the preceding concept maps, these differences in HSS show that the complexity of the concept map structure grew more during the construction of CM2 than CM3. The

increase in HSS for each of the three concept maps was more due to the width number than the depth number of each concept map. This means that the three concept maps grew more horizontally than vertically each time they were constructed. Such growth indicates that the complexity of each concept map structure was more due to the breadth of knowledge than the depth of knowledge I was learning.

Connectedness

Table 4.4 shows the numbers of chunks and crosslinks for each of the three concept maps. Column four of Table 4.5 shows the values of the connectedness of each of the three concept maps. These values were calculated by adding the numbers of chunks and crosslinks of each concept map from Table 4.4. The section that follows discusses how each of these variables contributed to the connectedness of each of these concept maps.

The chunks

The results show that the number of chunks in the three concept maps is 5, 8 and 14 respectively. These results show that CM3 had the highest number of chunks with CM1 having the least. This means that CM3 had more number of concepts grouped into clusters of ideas than each of the two preceding concept maps. The differences in chunk numbers show that the numbers of chunks increased by 3 from CM1 to CM2 and increased by 6 chunks from CM2 to CM3. The increase in the number of chunks from one concept map to another indicates that my level of knowledge with respect to the grouping and ordering of concepts into clusters of ideas was growing.

A closer inspection of the three concept maps reveals that 4 of the 5 chunks in CM1 were retained in CM2 suggesting that 4 new chunks contributed to total number of chunks in CM2. The disappearance of the Faraday's law chunk was as a result of the formation of a new chunk, the induced emf chunk, in CM2. CM3 reveals that 5 chunks from CM1 and 4 of the new chunks from CM2 contributed to the total number of chunks in CM3, suggesting that only 5 new chunks were formed in CM3. These results show that the disappearance and reappearance of the Faraday's law chunk was as a result that this chunk was continuing to evolve.

Crosslinks

The numbers of crosslinks for the three concept maps are 8, 11 and 15 respectively. The results indicate that CM3 had the largest number of crosslinks than the first two concept maps. The results indicate that the number of crosslinks increased by 3 from CM1 to CM2 and by 4 from CM2 to CM3. These results show that the level of connection between the concepts grew each time these concept maps were constructed. The results also confirm that my knowledge of the topic was growing since my ability to relate the concepts to each other was developing each time the concept maps were constructed.

Table 4.7 below shows how the crosslinks of each concept map were classified in terms of the kinds of concepts they were linking. The crosslinks were classified as the crosslink between: (1) the leading concepts of two chunks, (2) the leading concept of one chunk and the associated concept of another chunk, and (3) two associated concepts of two different chunks. The crosslink is depicted as CL, the leading concept as LC and the associated concept as AC in the Table.

Table 4.7: Classification of crosslinks in terms of concepts

Concept Map	No. of CLs	CLs between LCs of chunks	CLs between LCs and ACs of different chunks	CLs between ACs of different chunks
CM1	8	2	3	3
CM2	11	6	3	2
CM3	15	9	6	0

NOTE: CL: Crosslink; LC: Leading Concept; AC: Associated Concept

The Table reveals that the number of crosslinks between the leading concepts of two chunks, and the number of crosslinks between leading concept of one chunk and the associated concept of other chunk were increasing as the number of crosslinks between the associated concepts of separate chunks were decreasing from CM1 to CM3. The decrease in the number of crosslinks between associated concepts of different chunks and the increase in the number of crosslinks between the leading concepts of chunks indicate my ability to convert simple ideas into complex thoughts and the ability to connect these thoughts into meaningful knowledge structures.

The concept maps also revealed that some concepts had more than one crosslinks connected to them. For example, the ‘induced magnetic field’ concept in CM3 was crosslinked to the ‘Lenz’s law’, ‘Right-hand rule’, ‘increasing magnetic flux’ and ‘decreasing magnetic flux’ concepts. Such concepts revealed that my ability to connect different concepts grew as the study progressed. The ability to connect a group of concepts into coherent thoughts demonstrated that I was developing a deeper understanding of the topic.

Connectedness

The numbers representing the connectedness of the three concept maps are 13, 19 and 29 respectively. These values show that the level of connectedness grew each time the concept maps were constructed and that the level of connectedness was higher in CM3 than the preceding concept maps. The high number of crosslinks compared to the number of chunks in each concept map suggests that my ability to make meaning amongst the concepts contributed more than my ability to group concepts into meaningful ideas. Thus my understanding of the topic was more as a result of my ability to relate the concepts rather than to group them.

4.4.4 Conclusion of structural analysis

The analysis of the structure of the three concept maps show that all concept maps grew in the number of concepts I acquired during the study. This was confirmed by the way in which the number of concepts increased each time the concept maps were constructed. The increase in the complexity of each concept map structure every time the concept maps were constructed revealed that the concepts I had acquired were developing from simple thoughts into more complex coherent ideas about the topic. This gradual growth in the complexity of the concept map structures confirmed that my breadth and depth of knowledge of the topic was developing. The increases in the levels of connectedness from one concept map to the other confirmed my ability to group, order and connect ideas thus showing a deeper understanding of the topic.

4.5 Content analysis of the three concept maps

A qualitative typological approach was used to analyse the contents of the three concept maps. Typological analysis is an approach which involves breaking down the overall data into smaller sets of data based on predetermined typologies (Hatch, 2002). Typologies are predetermined topics used to separate data into categories or groups in the initial stages of data processing. According to Hatch, typologies are generated from theory, common sense, and/or research questions.

Typological analysis involves both the deductive and inductive methods of analysing data. The deductive approach is used to establish the typologies in the initial stages of data processing and the inductive method is used to probe the typologies further in order to establish patterns, relationships and themes that emanate from them. Hatch suggests that this type of analytical approach is suitable for processing artefact data with specific purpose in mind such as concept maps.

4.5.1 Initial data processing

Data transcriptions of the three concept maps was done before the initial data analysis could commence as the concept maps consisted of separate concepts and their linking words which needed to be transformed into complete ideas (see Appendix C). Each concept map was read through carefully to establish the propositions that emerged from its contents and these were recorded on separate sheets for each concept map. Data transcriptions were done in such a way that all thoughts were correctly captured because failing to do so would result in missing or misinterpreting an otherwise valuable data. The transcriptions as well as the actual concept maps were used as the sources of raw data to cross-check or double-check information whenever I was in doubt of the knowledge I was analysing.

Two typologies based on the research questions set forth in this study were used to divide the overall data of the concept maps. These typologies are ‘content knowledge’ and ‘instructional delivery’. All three concept maps were analysed with the intention of separating the data into two categories, namely data that related to subject matter content and data that related to the teaching of the topic. This was done by focusing

on the transcripts of data for each concept map and coding those parts of data that fit into the content knowledge typology with the same colour pen. A different colour pen was then used to highlight those parts of data that represented the instructional delivery typology.

Those parts of the data that were marked for the content knowledge typology were then read carefully to establish the main ideas that emerged from them. These main ideas were then recorded on a summary sheet marked content knowledge typology (see Appendix D). The same procedure was repeated to record the main ideas that emerged for the instructional delivery typology. However, during this period I encountered some problems as I could not decide the placement of some parts of the data. This problem was addressed by writing those parts of data in both typologies and then indicating them with a different colour pen to show that there was a possibility that these parts of data either belonged to both typologies or that there was another third typology that might be created.

Hough *et al.* (2007) recommend that one way to analyse the contents of concept maps is to explore all the content chunks of each concept map constructed in order to assess how conceptual development of the knowledge networks of the mapper changed during learning. According to Hough *et al.*, a content chunk consists of a group of propositions (concepts connected by linking words to form complete ideas) belonging to the same chunk of which its leading concept represents the name of the chunk. For example, all the concepts together with their linking words belonging to the chunk of which its leading concept is induced current represent a content chunk called 'induced current'.

Thus the main ideas in the summary sheet of the content knowledge typology were organised in terms of the content chunks that emerged from the data. These content chunks were magnetic field strength, magnetic flux, changing magnetic field/flux, induced emf, induced current, induced magnetic field and Lenz's law. Other ideas which did not belong to the content chunks emerged as the initial processing of the data was done. These ideas were not part of the content chunks but were connected directly to the core concept as free-standing ideas. These ideas were listed as free-standing ideas below the EMI concept. The summary sheet of the instructional

delivery typology consisted of a list of free-standing ideas which emerged from the concept maps.

Hatch (2002) refers to the process of creating summary sheets as data reduction. Data reduction serves the purpose of reducing large amounts of data into smaller manageable data for analysis. In this study, the creation of summary sheets for each typology was meant to narrow the focus of analysis so that the main ideas that emerged from the raw data could be studied. Care was taken to ensure that all the relevant ideas of the topic were included in these summary sheets because failing to do so would affect the 'complexity, richness and depth' (Hatch, 2002) of the raw data. The supervisor compared the concept maps with the summary sheets for verification. Omissions were added and errors rectified before data analysis could commence.

4.5.2 Typological analysis

Hatch (2002) maintains that although typological analysis starts with a deductive step, it does not preclude the researcher from using the inductive approach to analyse data. According to Hatch, inductive procedures can be applied to fill in the gaps that might not be covered by the deductive procedures. Thus, this study used a qualitative inductive approach to analyse the typologies from within and across as I believed that this approach would assist me in uncovering the salient dimensions of data in ways that could not be possible with the deductive approach only. Inductive analysis begins with an examination of the particulars within the data, moves to search for meaning across individual observations, and ends with the argument of the status of the general statements made (Hatch, 2002).

The summary sheets of the two typologies were used to search for meanings that could emerge from the typologies. Each typology was read through carefully searching for meanings that came from the data they contained. Each typology was first searched from across and then from within to establish potential themes that emerged from them. The section that follows gives a brief discussion of how each typology was searched for meaning.

Content knowledge analysis

This typology was first analysed across as the data in it was already organised into content chunks. The whole typology was read carefully across and eight categories were established and recorded in another summary sheet. A summary of the categories is shown in Table 4.8 below while the full version of the list of categories is attached in appendix E.

Table 4.8: Summary of the list of categories in the content knowledge typology

Category	Concepts
EMI process	Magnetism produces electricity; transforms kinetic energy into electrical energy.
Main concepts	Magnetic field strength; magnetic flux; changing magnetic field; induced emf; induced magnetic field; induced current
Laws and rules	Faraday's law; Lenz's law; R-H rule; Ohm's law
Definitions	Magnetic field strength; magnetic flux; changing magnetic field; induced emf; induced magnetic field; induced current; EMI.
Equations	$\varphi = BA$, $\varphi = BA\cos\theta$, $\Delta\varphi = \Delta BA = (B_f - B_i)A = (\varphi_f - \varphi_i)$, $\varepsilon = -N\Delta\varphi/\Delta t$ and $\varepsilon = IR$
SI units	$1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$;
Magnitudes	Induced current; induced emf.
Directions	Induced current, induced emf, induced magnetic field, magnetic flux, changing magnetic field
EMI application	Microphones; seismographs; inductions stoves; generators; transformers

The search for meaning across the typologies revealed that:

- EMI is a process involving the generation of electricity using the effects of magnetism.
- The EMI topic consists of six main concepts, namely magnetic field strength, magnetic flux, changing magnetic flux, induced emf, induced magnetic field and induced current.
- There are rules and laws that govern the process of EMI. These are Right-hand rule, Faraday's law, Lenz's law, and Ohm's law.
- Each concept of EMI is structured in such a way that it consists of definition(s), equation(s), units of measurement, factors influencing its magnitude and direction (vector nature), and how each concept is applied in everyday situations.

The search for meaning within the categories (use Table 4.8) revealed that:

- A changing magnetic field produces a current, just like an electric field in electric circuits (category 1).
- The effects of a changing magnetic field (magnetic flux that increases or decreases and its magnetic field strength) induce emf, current and its magnetic field (category 2).

- The laws and rules of EMI relate the vector nature (magnitude and direction) of these concepts (category 3).
- The main concepts of EMI are somehow defined in terms of the changing magnetic field concept (category 4).
- The induced emf equation (Faraday's law equation) is a symbolic representation of all the concepts of EMI (category 5).
- The relationships amongst the main concepts of EMI can be expressed in terms of: $1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$ (category 6).
- All the main concepts of EMI are vector quantities of which the factors that influence their magnitudes and directions should be known (categories 7 & 8).
- The EMI process is applied in equipment such as transformers, generators, microphones, seismographs and induction stoves (category 9).

Instructional delivery typology

The whole typology was also read carefully within and across searching for meaning in the entries recorded in the summary sheet. Ten categories were established and recorded in another summary sheet. A summary of the categories is shown in Table 4.9 below while the full version of the list of categories in this typology is also attached in appendix E.

Table 4.9: Summary of the list of categories in the instructional delivery typology

Categories	Concepts
Teacher/learner actions	Solve; demonstrate; explain; apply; use; convert; groupwork
Lesson indicators	L1; L2; L3.1; L3.2; L3.3; L4
Representations (textual/visual)	Words; pictures; artefacts
Teacher awareness	• Not for grade 11; • Solving strategies; unit conversions; area formulae
Learning outcome 3	Microphones; seismographs; card swiping machines; generators; transformers.
Learning and Teaching Support Material (LTSM)	Magnets; coils; solenoids; ammeters; galvanometers; transformers; generators.

NOTE: L1- Lesson 1; L2- Lesson 2; L3-Lesson 3; L4- Lesson4

The search for meaning in this typology (use Table 4.9) revealed that:

- Verbs such as solve, demonstrate and explain represented some of the actions that needed to be taken by either the teacher or learners during instructions (category 1).

- Lesson indicators which were attached in some of the leading concepts in the third concept map indicated how I intended to structure the sequence of the lessons when teaching this topic (category 2).
- Textual and visual representations would have to be used during instruction to promote conceptual understanding (category 3).
- The phrase 'not for grade 11' and phrases like 'solving strategy', 'unit conversions' and 'area formulae' show that the teacher should be aware of actions to take and/or not to take during instructions (category 4).
- Learners need to be exposed to devices that use the process of EMI (category 5).
- Apparatus such as magnets, coils and galvanometers need to be used to develop conceptual understanding of the topic (category 6).

Mention was made about a possible typology that may be created as I was not sure of the placement of some of the data. This data concerned the classification of concepts such as microphones, seismographs, induction stoves, generators and transformers. After some consideration it became clear to me that these concepts belong to the two typologies because in the case of content knowledge typology they represented instances of where EMI was applied in everyday life. On the other hand, they represented one of the learning outcomes that needed to be achieved in the curriculum. This learning outcome expects learners to be competent in "the nature of science and its relationship to technology, society and the environment" (DoE, 2003, p. 12). Thus, these concepts were also included in the instructional delivery typology because they represent an aspect of teaching that needed to be attained.

4.5.3 Results of content analysis

Several themes emerged in the analysis of the two typologies. These themes are discussed below using the Rollnick *et al.*'s (2008) model of PCK which I chose as the theoretical framework for the study. The Rollnick *et al.*'s model used 8 components of teacher knowledge which are evenly classified into two categories as the domains and manifestations to capture aspects of learning and teaching I wished to attain in the study. The domains components of teacher knowledge are subject matter knowledge, general pedagogical knowledge, knowledge of learners and knowledge of the context. The manifestations are subject matter representations, teaching strategies, curricular saliency and assessment.

Subject matter knowledge

The results of the analysis of the concept maps reveal that EMI is a process that involves the generation of electricity using the effects of magnetism. During this process, a changing magnetic field induces an emf in the conductor which in turn induces an electric field. This electric field induces a current in the conductor which produces its own magnetic field. The two opposing magnetic fields interact to produce a magnetic force. The relative motion of the magnetic field and the conductor results in kinetic energy being transformed into electrical energy.

The results of the analysis show that EMI consists of six main concepts, namely magnetic field strength, magnetic flux, changing magnetic field/flux, induced emf, induced current, and induced magnetic field as already reported herein. Each main concept is structured in such a way that it consists of definition (s), equation(s), units of measurement, factors influencing its magnitude and direction, and how each concept is applied in everyday situations. Each of these concepts (excluding changing magnetic field) is defined in terms of a changing magnetic field. For example, induced current and induced emf are defined respectively as:

> Current produced by a changing magnetic field and;
> Voltage produced by a changing magnetic field.

The results also show that there are laws, rules and principles that govern the process of EMI. These are the Faraday's law, Lenz's law, Right-hand rule and the Principles of EMI. The rules and laws used in EMI relate the vector nature (magnitude and direction) of the six main concepts to one another. For example, Faraday's law relates the magnitude of the induced emf to the rate of change of magnetic flux whereas the right-hand rule relates the direction of induced current to its magnetic field. The first Principle of EMI shows how a changing magnetic field induces other quantities so that current is produced in the conductor.

These results show how the structure of the EMI content is organised, how each of the main concepts are structured, as well as the laws, rules and principles governing the process of EMI. These results confirm Shulman's view of subject matter knowledge.

Shulman (1986) refers to subject matter knowledge as the amount and organisation of knowledge as viewed by the domain experts in a particular discipline. According to him, this knowledge includes knowledge of facts or concepts, laws, principles, theories as well as the structures governing the discipline.

Subject matter representations

The results show that a variety of representations were used in the concept maps to represent subject matter. Words such as 'words', 'pictures' and 'artefacts' in the concept maps suggests that textual and visual representations would be used during instruction to promote conceptual understanding of the topic. The inclusion of apparatus such as magnets, coils and galvanometers in the concept maps suggests that scientific tools would be used as forms of representations to transform subject matter knowledge into knowledge suitable for conceptual understanding.

The equations listed in the concept maps represent ways of representing subject matter. Equations are symbolic representations of subject matter which when interpreted correctly can result in conceptual understanding. For example, the equation $\varphi = BA$ can be used to define magnetic flux as:

> product of magnetic field strength and the area enclosed by a conductor.

This equation can also be used to identify the factors influencing the magnitude of magnetic flux, namely the magnetic field strength and the area enclosed by the conductor.

Shulman (1986) refers to subject matter representations as forms of representations used by the teacher to make the subject comprehensible to learners. The variety of subject matter representations discussed above indicated my intention to use representations to transform subject matter into knowledge suitable for teaching. Geddis, Onslow, Beynon, and Oesch (1993), however warn that the choice of subject matter representations should be carefully made as failing to do so may result in the meaning of phenomena being distorted.

Teaching strategies

The results show that action verbs such as ‘solve’, ‘demonstrate’, and ‘explain’ were used in the concept maps. These verbs show some of the actions that either the teacher or learners could take to develop their understanding of the topic. These verbs in turn represent some of the teaching strategies that could be followed to facilitate the course of instruction. Based on these action verbs, it means that teaching strategies such as problem-solving, demonstrations, groupwork and explanations could be used to facilitate learning.

The lesson indicators (L1, L2, L3.1, L3.2, L3.3 and L4) attached in the core and main concepts of the topic also represent a teaching strategy. These indicators represent how I intended to present the lessons in a particular logical sequence to promote conceptual understanding and coherence. For example, the lesson indicator L1 attached to the EMI concept in CM3 indicated my intention to introduce the concept of EMI first before teaching the other main concepts in the sequence indicated in the concept map.

Rollnick *et al.* (2008), refer to teaching strategies as the approaches employed by the teacher to facilitate the course of instruction. According to Rollnick *et al.*, these strategies include methods that the teacher employ to sequence the lessons, questions asked to assess progress as well as learner activities provided to direct the course of the lesson.

Curricular saliency

The results show some instances of teacher knowledge indicating curricular saliency. The phrase ‘not for grade 11’ linked to the equation $\varphi = BA\cos\theta$ in the concept maps indicate teacher awareness of what to include or exclude in instruction. This equation was included in the concept maps to make me aware that the equation $\varphi = BA$ could also be written in this way for instances where the magnetic field was not perpendicular to the area enclosed by the conductor. Depending on the level of learners’ understanding, this equation could be used as an expanded opportunity. The lesson indicators used in the concept maps to show the order of the lessons also

indicate curricular saliency in that they show how the structure of the content is organised.

Ohm's law equation was included in CM3 to show a link between the topics electric circuits and EMI. Learners had learned about this law and its application in solving problems involving electric circuits previously. Thus the inclusion of this law in this topic served two purposes: (1) to promote conceptual progression and (2) to show a relationship between the two topics. This equation would assist learners to solve problems involving induced current as the EMI equations used in grade 11 do not have an equation that has current as one of the quantities. Thus, the equation $\varepsilon = IR$ served the purpose of linking the two topics as the induced emf equation is $\varepsilon = -N\Delta\varphi/\Delta t$ and to promote conceptual progression and coherence.

The results discussed above show teacher awareness of what to include and/or exclude when teaching the topic, how the lessons should be sequenced to promote learner understanding of the topic and how this topic should be linked to other topics. These results confirm Rollnick *et al.*'s (2008) and Geddis *et al.*'s (1993) views of curricular saliency. Rollnick *et al.* refer to curricular saliency as the conscious decisions that the teacher make with regards to what comes before and after the topic, what to include or omit in the topic as well as how a particular topic links with other topics within and outside the subject. Geddis *et al.* maintain that such decisions are determined by teacher's knowledge of the structure of the content, the learners being taught and the purpose for teaching the topic.

Assessment

The results of the concept maps analyses do not show explicitly the activities or tasks that would be provided for assessment. However, the phrase 'solve problems' suggests that learners would be given activities to solve topic-related problems. The phrase 'use magnets, coils and galvanometers to demonstrate or provide groupwork' in CM3 suggests that learners might be engaged in a groupwork or practical activity where their manipulative and procedural skills would be assessed. Furthermore, the proposition 'EMI is applied in transformers, generators and induction stoves' might

suggest that learners would be exposed in activities where their understanding of the topic would be assessed with what they experience outside the classroom.

Knowledge of learners

The inclusion of 'ε = IR (Ohm's law)' in CM3 indicates that I was aware of what learners had learned prior to the teaching of EMI. The phrases 'solving strategy', 'unit conversion' and 'area formulae' connected to the equations in CM3 suggest that I was aware of my learners' learning difficulties. I was aware of the mathematical problems encountered by the learners with regards to steps followed in solving problems, their inability to convert from one unit to the other and their difficulty to work with area formulae. Furthermore, writing the change in magnetic flux as:

$$\Delta\varphi = \Delta BA = (B_f - B_i)A = \varphi_f - \varphi_i$$

instead of just:

$$\Delta\varphi = \Delta BA$$

suggests that I was aware of the difficulty the learners had with working with 'changing quantities'. Based on previous interactions I had with these learners, I knew that they had difficulty understanding the concept of 'change'. Thus, this concept had to be explained to the learners once more as the difference between what took place at the end and at the start of a situation.

I was also aware of other learners' language difficulties judging by the way I used words such as 'pictures' and 'artefacts' in the concept maps. The inclusion of these words in the concept maps suggests that I saw the need of using visual representations in the lessons in order to assist my learners in overcoming language barriers associated with the understanding of the topic.

General pedagogical knowledge

The results of the analyses of the concept maps show some examples of general pedagogical knowledge in that teaching strategies to be employed during instruction are mentioned in the concept maps. These strategies include problem-solving strategies; demonstrations; explanations as well as lessons sequencing intended to assist learners understand the topic. The phrase 'provide groupwork' in the concept

maps suggests that classroom organisation would take place as learners need to reorganise themselves to take part in a groupwork. Moreover, groupwork demands that learners' cognitive abilities and their social behaviour should be considered so as to ensure that effective learning takes place.

General pedagogical knowledge refers to knowledge of basic skills required for teaching. According to Rollnick *et al.*, general pedagogical knowledge include knowledge of what counts as good teaching, the best teaching approaches, different learning theories, classroom organisation and management, physical and psychological behaviour of learners, and specific educational purposes.

Knowledge of context

The results show teacher awareness of the resources to be used during instruction. The phrase 'magnets, coils, and galvanometers' represent the resources that the mapper intended using during instruction. The phrases 'microphones, seismographs and card swiping machines' and 'transformers, generators and induction stoves' represent some of the resources that the mapper might use in the form of pictures to link what learners have learned in the classroom with the devices that learners usually encounter in their everyday life.

4.5.4 Conclusion of content analysis

The results of content analysis show that there is learning that took place with regards to the development of my content knowledge. During the construction of concept maps my knowledge of the concepts, laws, rules and principles as well as knowledge of the organisation of the structure of EMI developed. The results also show that during concept mapping, other aspects of teaching also developed. These aspects of teaching include my ability to identify subject matter representations, teaching strategies and possible assessment strategies that I would employ when teaching this topic; knowledge of what to teach and not to teach, how to link this topic with other topics as well as how to sequence the lessons so that my learners could better understand the topic (curricular saliency); understanding of learners' prior knowledge and their learning difficulties (knowledge of learners); awareness of learners'

cognitive abilities and how classrooms should be organised so that learners could learn at their optimal level (general pedagogical knowledge); and the ability to select relevant resources that would assist learners to develop understanding of the topic (knowledge of context).

4.6 Overall conclusion

The use of concept maps in this study was an attempt to assess my knowledge development that took place when I was learning to understand the topic on EMI. Concept mapping was a reflective attempt on my side to monitor my metacognitive ability in terms of how my learning evolved over the period of learning. This entailed constant revisiting of the learning process with a purpose of establishing gaps in my knowledge, identifying relationships and tracing connections between my prior knowledge and the new knowledge I was acquiring from time to time.

The analysis of the structural components of the concept maps was an attempt to monitor growth in terms of the development of my content knowledge regarding the topic. The results show that there was growth in conceptual acquisition as the total number of concepts that I learned increased during my participation in the study. The growth in the complexity of the structures of the concept maps indicated that not only was my knowledge just developing in terms of conceptual acquisition but also in terms of the ability to develop simple thoughts into complex ideas. This was confirmed by my ability to combine discrete concepts using linking words to form complete thoughts referred to earlier as propositions. The growth in levels of connectedness of the concept map structures demonstrated how these thoughts were interrelated to form a deep understanding of the topic. This was revealed by how I grouped these thoughts into content chunks, organised them into a series of chronological lessons and link them to each other.

Content analysis of the concept maps was an attempt to explore the amount and organisation of content knowledge that I learned. The results show that learning occurred during the study as I was able to gain knowledge with regards to understanding the concepts, laws, rules and principles that govern the process of EMI as well as how the structure of the topic was organised. However, the results also

show that during the process of concept mapping, other aspects of teacher knowledge were also coming to the fore with regards to how I was going to teach this topic. These aspects of teacher knowledge include teaching strategies and instructional representations, curricular saliency and assessment, knowledge of learners and context as well as general pedagogical knowledge.

The emergence of these aspects of teacher knowledge is understandable considering that while I was constructing the concept maps, I was also concerned about how I was going to teach this topic to my learners in such a way that it would be easy for them to understand it. During the construction of the concept maps I was concerned about the breadth and depth of the topic to be covered, knowledge that learners were likely to bring to class and their learning challenges, methods and representations that I would use to make the content comprehensible, instructional resources and assessment activities that could be used to assess learners' understanding.

The emergence of these aspects of teaching during concept mapping suggests that not only was I developing knowledge of the content but also transforming this content knowledge into knowledge for teaching. Rollnick *et al.* refer to this transformation of content knowledge into knowledge comprehensible to others as PCK. The emergence of the manifestations in the concept maps such as teaching strategies, instructional representations, curricular saliency and possible assessment activities suggests that concept mapping assisted me in developing and capturing those aspects of teacher knowledge that contribute towards the development of PCK. It is through these manifestations that I was able to identify the development of my PCK with respect to content knowledge, general pedagogical knowledge, knowledge of learners and knowledge of the context.

Hough *et al.* (2007) indicate that concept maps in conjunction with reflective writing are a means of assessing participants' understanding in specific topics, especially those that may result from professional development. The construction of concept maps as well as their analyses thereof assisted me in reflecting, capturing and documenting my PCK so that I could be able to assess what I learned about the topic. Articulating my PCK in this way would also enable others to assist me in finding gaps in my knowledge about the topic. Loughran *et al.* (2004) suggest that one way to

capture ones' PCK is to document it in such a way that its tacit nature could be revealed.

Chapter 5 discusses how the CoRe on EMI was analysed. A PaP-eR is used to reveal the salient features of the topic that I learned during the entire study. This PaP-eR focuses on critical instances that I considered as significant towards the development of my PCK regarding content knowledge.

CHAPTER 5

ARTICULATING PEDAGOGICAL CONTENT KNOWLEDGE

5.1 Introduction

This chapter discusses how the development of a CoRe and a PaP-eR assisted me in capturing, portraying and articulating my pedagogical content knowledge on EMI. The chapter first looks at how I constructed the CoRe and how the CoRe assisted me in realising aspects of teacher knowledge that contributed towards the development of my PCK. It then proceeds to discuss the PaP-eR which illuminated some of the salient features of my learning and how I intend to use these features to enhance learner understanding. The chapter concludes by looking at how both the CoRe and the PaP-eR contributed to the overall development of my PCK on EMI.

5.2 The CoRe

5.2.1 The construction of the CoRe

The CoRe was constructed using a format suggested by Loughran *et al.* (2006). Refer to appendix G for the CoRe on EMI. The horizontal columns consisted of four big ideas which were developed from the knowledge I learned from the curriculum documents and the various textbooks that I consulted during the period of study. These big ideas are: (1) a changing magnetic field induces an emf that causes an electric field to set up an induced current in the conductor; (2) the induced current moves in a direction so that its magnetic field opposes the changing magnetic field that produced it; (3) it is the relationship between the induced emf and the rate of change of magnetic flux that drives the process of EMI and hence the generation of electric current; and (4) a changing current in one conductor induces an emf which sets up an induced current in a nearby conductor.

The fourth big idea is included in the CoRe just to complete the big ideas that emanated from the various text documents that I consulted during the construction of the CoRe. This big idea should however not be taken as part of the study as during the

study it was decided between my supervisor and I that it would be better to leave this big idea out so as to limit the scope of the study. Thus, its inclusion in the CoRe has three purposes: (1) to give the reader an idea of the big ideas that I believe form the core of the topic on EMI; (2) I intend using this CoRe as a basis for my future presentation and development of my learning and teaching of this topic; and (3) I will be referring to this big idea when presenting what I learned from the study regarding the principles that govern the process of EMI.

The vertical rows of the CoRe consisted of prompts which probe each big idea regarding its learning and teaching. The first prompt focuses on teacher's intentions to teach this topic as specified by the curriculum, i.e. what is it exactly that the teacher wants the learners to know about this topic? The second prompt looks at the reasons why this topic should be taught to learners at a particular grade level. This prompt links what is taught in the classroom with what learners experience in their everyday discourse regarding the topic. The third prompt refers to knowledge that the teacher knows but because of the complexity of the topic would wish to reserve or hold back until the learners are ready to learn it. The fourth prompt refers to potential challenges and limitations that might hinder learners from understanding the topic.

The fifth prompt of the CoRe refers to teacher's knowledge about learners which through his/her experience serves as a springboard to teaching the topic. This prompt refers to learners' commonly held ideas, the manner in which the learners generally respond to the topic as well as specific teaching and learning situations developed through the topic (Loughran *et al.,* 2006). The sixth prompt unpacks teacher's contextual knowledge about the learners and his/her general pedagogical knowledge that influences his/her approach to teaching the topic the way s/he does. The seventh prompt focuses on the teaching procedures that the teacher employs and the reasons for using them in order to achieve the intended outcomes. The last prompt focuses on specific ways of monitoring learners' learning progress around the topic. These include forms of assessments such as questioning and activities used to probe their understanding.

5.2.2 Discussion of the CoRe

Big ideas of the CoRe

The first big idea was derived from the big science idea which states that '*a changing magnetic field induces an electric current in a closed conductor*'. This science idea only shows the cause-effect parts of the process of EMI without indicating other steps involved in-between a changing magnetic field and an induced current. To assist learners to better understand the process of EMI, I had to transform this big science idea in such a way that it linked with what learners have learned in electric circuits and magnetism. This was done by including the induced emf and electric field concepts as a means that would help them understand how the EMI process is achieved. Figure 5.1 shows how this big science idea was transformed into the first big idea.

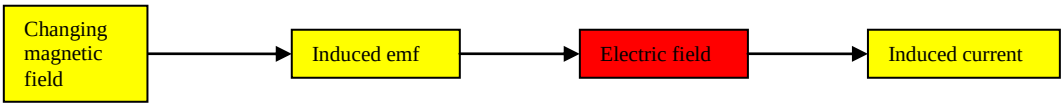


Figure 5.1: Representation of the first big idea

The inclusion of the other two concepts (induced emf and electric field) in the big science idea was meant to indicate to the learners that the EMI process involves several steps rather than the one step reflected in the big science idea. These steps are represented by the following propositions as:

- *A changing magnetic field sets up an induced emf between the ends of the conductor;*
- *The induced emf sets up an electric field in the conductor; and*
- *The electric field causes the charged particles in the conductor to move (induced electric current).*

The first big idea is the amalgamation of the three steps involved in the EMI process and it is stated as '*a changing magnetic field induces an emf that causes an electric field to set up an induced current in the conductor'*. The inclusion of the induced emf and electric field concepts in the big science idea served two purposes: (1) to indicate

the complete process of producing electric current using the changing magnetic field; and (2) to link what learners had learned prior to this topic.

The second big idea is an adaptation of another big science idea called the Lenz's law. This big idea states that '*the induced current moves in a direction so that its magnetic field opposes the changing magnetic field that produced it'*. This idea has several implications associated with it. Firstly, it reveals what learners had learned earlier on that electric charged particles produce their own magnetic field when they move. Secondly, it reveals that there are two magnetic fields involved in the process of EMI namely, the changing magnetic field that sets up the induced current and the magnetic field that is set up by the induced current itself. Thirdly, it shows that the two fields always oppose each other every time a current is induced.

The fourth implication suggests a method that can be used to determine the direction of the induced current in the conductor when the direction of motion of the changing magnetic field is known or vice versa. Knowing the direction of motion of the changing magnetic field and that this field always opposes that of the induced magnetic field assists in determining the direction of the induced current. The fifth implication implicitly reveals that the interaction of the two fields results in the establishment of a magnetic force between the magnet and the conductor. This force is responsible for the relative motion of the magnet and the conductor.

The second big idea can be regarded as the extension of the first big idea to explain the whole process of EMI. This idea can be broken down into the following propositions: (1) *the induced current produces its own magnetic field; and* (2) *this induced magnetic field opposes the changing magnetic field*. These two propositions when combined with the propositions of the first big idea resulted in the statement which I regard as explaining the complete process of EMI. This process states that: *'a changing magnetic field induces an emf that causes an electric field to set up an induced current in the conductor. The induced current produces its own magnetic field which opposes the changing magnetic field that has produced it'.*

The combination of the propositions of the two big ideas can be represented as shown in Figure 5.2 below.

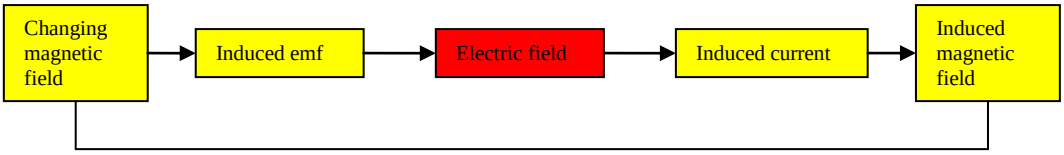


Figure 5.2: The complete process of EMI

This EMI process is a cyclic process that involves the relative motion of the two opposing magnetic fields and this relative motion is the one that drives the process of EMI.

The third big idea states that *'it is the relationship between the induced emf and the rate of change of flux that drives the process of EMI and hence the generation of electric current'.* This big idea was derived from another big science idea that governs the process of EMI. This science idea is the Faraday's law equation, namely $\varepsilon = -N\Delta\varphi/\Delta t$. Faraday's law as stated in many school textbooks was not used to formulate the third big idea because it focuses only on one factor that influences the induced emf. This law states that '*the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux'*. Using this law the way it is stated in the school textbooks suggests that the magnitude of the induced emf depends ***only*** on the rate of change of magnetic flux when this is not the case.

Using Faraday's law equation reveals that the magnitude of the induced emf depends on two factors, namely the rate of change of magnetic flux and the number of turns in the conductor. Secondly, the equation also provides the directional relationship between these two concepts, namely that the direction of the induced emf always opposes that of the rate of change of flux (indicated by the negative sign in the equation). Thus, the use of the equation covers both the factors that influence the magnitude of the induced emf as well as the directional relationship between the two concepts as compared to the law as stated in the textbooks which only focuses on one factor that affects the magnitude of the induced emf.

This equation also provides a better platform for the learners to understand that the relationship between the induced emf and the rate of change of magnetic flux is the one that actually drives the process of EMI. Understanding that it is the rate at which

the magnetic flux changes that eventually leads to the generation of electric current helps them to conceptualise the process of EMI. For example, using $\varepsilon = -N\Delta\varphi/\Delta t$, it can be shown that the change of magnetic flux is derived from the magnetic flux ($\Delta\varphi = \Delta BA$) and that the magnetic flux is linked to the magnetic field strength ($\varphi = BA$). These concepts are linked to the induced emf by the same equation and the induced emf is in turn linked to the induced current by the Ohm's law equation $\varepsilon = IR$. Thus, all the concepts of EMI are linked one way or the other to the induced emf by the Faraday's law equation.

The use of the equation to formulate the big idea was meant to address one of the misconceptions commonly held by many learners with regards to the rate of change of magnetic flux. Sağlam and Millar (2006) suggest that learners have the tendency to confuse 'the change of magnetic flux' with 'the rate of change of magnetic flux' when using the Faraday's law equation. Thus, when discussing this big idea it is imperative that the concept of 'rate' is explicitly conveyed to the learners. The 'rate' concept relates any change of a physical quantity with respect to something (as in $\Delta y/\Delta x$ and in most physics concepts Δx is Δt); however, in this case it measures how fast the motion of the change of flux takes place in a specific time.

Prompts of the CoRe

First prompt
(What I intend the learners to learn about these ideas?)

The first prompt of the CoRe lists those aspects of content knowledge that I intended my learners to learn so that they could better understand each big idea. For example, the first prompt of the first big idea shows how I intended introducing the topic of EMI to the learners. It shows my intention of using the relative motion of the magnet and conductor to induce a changing magnetic field that generates electric current. This was done to indicate to the learners how the effects of a changing magnetic field influence the vector nature (magnitude and direction) of the induced current. The first prompt of the first big idea also indicates concepts that the learners would have to contend with to better understand the process of EMI.

The first prompt also shows how I intended to sequence the lessons of the topic so as to promote conceptual progression. The lessons were sequenced in such a way that the ideas were first introduced in a simple way and then later on revisited to build upon their abstract nature. For instance, in the first lesson the teacher gives the learners the impression that a changing magnetic field is the one that results in the generation of electric current. However, in the third lesson they are informed that it is the rate of change of magnetic flux that in effect results in the induction of current. Lesson sequencing requires that the teacher has a better understanding of the content, is aware of what to include and exclude in a particular lesson, and is aware of the potential learners' challenges.

The first prompt also reveals how the structure of the topic looks like. The prompt includes concepts, laws, rules and principles that govern EMI spread throughout the three big ideas. The first prompt of the third big idea also shows that each concept of EMI consists of definitions, equations, units and factors that influence its vector nature. The inclusion of these aspects of content knowledge in the first prompt indicates how my knowledge structure of the topic had developed as I constructed the CoRe. These aspects also reflected my intention to assist my learners to develop a deeper understanding of the topic with regards to conceptual rather than procedural understanding.

The first prompt of the CoRe also included some of the aspects of content knowledge that the grade 11 curriculum does not explicitly regard as fundamental to understanding the topic. These are the magnetic force concept and Lenz's law. The implicit discussion of Lenz's law in the curriculum is somehow of concern as this law is the one that assists learners to determine the direction of the induced current. The right-hand rule alone does not really assist learners to determine the direction of the induced current as they first need to be aware of the existence of the induced magnetic field that opposes the changing magnetic field before they can apply the rule. Learners also need to understand the magnetic force concept so that they can understand what causes the magnet to be attracted or repelled when inserted in a closed conductor like a coil.

Second prompt

(Why is it important for the learners to know these ideas?)

This prompt looks at the educational aims of teaching this topic to learners at this grade level. Up until this topic, learners have been taught the topics on electricity and magnetism as two separate entities. The inclusion of this topic in the grade 11 curriculum is meant to indicate to the learners that these two topics coexist. This suggests that none of these topics can exist without the other. Thus, the first purpose of the topic on EMI is to link what they have learned in the previous topics with the topic on EMI.

The second aim of teaching this topic is to extend the knowledge that learners have learned about EMI with what they experience in their everyday discourse. Learners interact with devices such as microphones, tape or disk recorders and credit card swiping machines in their everyday life without knowing that these devices use the process of EMI. Thus, the second prompt afforded me the opportunity to identify aspects of learning that would enable the learners to connect what they learned in EMI with what they experience in their everyday discourse as well as to better understand the importance of this topic in relation to science, technology and society.

Extending the knowledge that learners have learned to their everyday experiences also help them to move away from some of their commonly held ideas that are naïve. For example, learners generally think that a device such as a microphone only uses electricity to transmit sound. Little do they know that this device actually uses the effects of a changing magnetic field to transmit sound into electric signals that are eventually received by the loudspeakers (Giancoli, 2005).

Thus, the second prompt enabled me to link learners' prior knowledge and their everyday discourse with the topic on EMI. This prompt also gave me the opportunity to engage them in activities that would assist me to identify and address some of their primitive ideas. These issues reveal teacher awareness of learners' potential challenges, awareness of contextual issues through which these should be approached and the educational purposes of addressing such issues.

Third prompt

(What else I might know about these ideas that I do not intend learners to know yet?)

This prompt looks at the aspects of learning and teaching which the teacher has to suspend for a while to ensure that conceptual progression in each big idea is set out as planned. Knowledge concerning subsequent big ideas was withheld from the learners so that they could first contend with what was expected of them in the current big idea. The purpose of doing this was to ensure that learning focused on what they were supposed to learn at the time as well as to minimise any confusion or distraction that might cause them to develop conceptual misunderstanding of the big idea under discussion.

For example, when discussing the first big idea no mention of the magnetic field induced by current is made because my intention is to stress the idea that it is the changing magnetic field that produces current. Including the magnetic field induced by current here may result in learners being uncertain as to which of the two fields is responsible for the generation of the induced current. This may also result in one being compelled to introduce the magnetic force concept as some learners may be aware that the interaction of two or more fields of the same kind results in a force. Such deviation may thus result in the objectives of the lesson being lost along the way.

This prompt also reveals the importance of how the teacher should carefully choose what needs to be taught at a particular stage of learning and grade level. Withholding certain aspects of knowledge to be learned demands that the teacher should make informed decisions regarding what needs to be taught and left out for learners to have a better understanding of the topic. Such demands require that the teacher should have adequate knowledge of the topic, knowledge of the learners, and knowledge of the context through which learning takes place.

Fourth prompt

(Difficulties/limitations connected with teaching these ideas)

This prompt refers to the potential learning challenges that learners are likely to encounter during the teaching of this topic. These include misconceptions that learners bring to the lesson as well as limitations that are brought by representations such as models and analogies (Loughran *et al*., 2006). In this CoRe, most of the misconceptions that were included in this prompt are based on the literature that I read about the topic. These include misconceptions identified by various authors in Sağlam and Millar (2006), Sağlam and Millar themselves, and Thong and Gunstone (2008) which were discussed in chapter 2 of the study.

The most apparent misconception that I anticipated would pose a challenge to my learners relates to an idea of a changing magnetic field producing a current. This misconception was based on the fact that I did not envisage a magnetic field producing a current. My failure to understand this idea was based on the misconception that electric charged particles can only be set up by an electric field and no any other field. It never crossed my mind that electric fields can be generated by any source of emf other than a battery (although other sources of emf are mentioned in electric circuits). Thus, this misconception was as a result of the misconception that I transferred directly from the electric circuits.

Perhaps another potential learning difficulty that I expected would pose a challenge to my learners concerned their inability to interpret diagrams. Some textbooks use diagrams such as those shown in Figure 5.3 below to explain how the direction of the induced current produced by a changing magnetic field would flow in a coil.

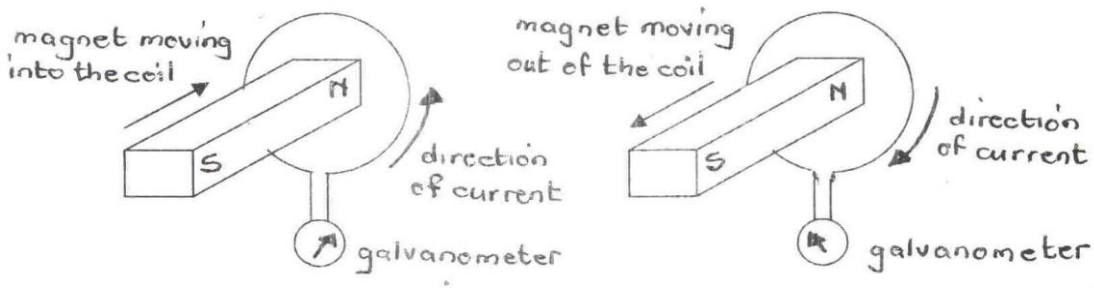


Figure 5.3: Diagrams used by some school textbooks (Hendricks, Long, Sadeck & Spies, 2009)

Although these diagrams are meant to promote learning, they may be misconstrued by the learners to mean that: (i) a magnet moving towards a coil causes the current to flow anticlockwise, and (ii) a magnet moving away from the coil causes the current to flow clockwise – which is not always the case.

Fifth prompt
(Knowledge about learners' thinking which influences the teaching of this idea)

This prompt looks at learners' commonly held ideas which influence the teaching of this topic. In this prompt I focused on learners' knowledge that they had to transfer from previous topics since it was the first time that I taught this topic to them. This includes knowledge that they have learned in mechanics, electricity, magnetism and mathematical skills required to solve EMI problems. In mechanics learners have learned about the concepts of change and rate as well as Newton's third law of motion which were the requirements for understanding this topic. In magnetism they learned about magnetic fields and how these can be represented using magnetic field lines. In *electromagnetism* they learned that electric charges produce a magnetic field when they move.

The idea of electric charges producing a magnetic field would assist learners in understanding the origin of the magnetic field produced by the induced current. Newton's third law would assist in helping learners understand the origin of the magnetic force exerted on the magnet and conductor when the two opposing magnetic fields interact. The concepts of change and rate would assist them in understanding that it is actually the rate (measure of how fast or slow) at which the magnetic field changes that determines the magnitude of the induced emf and thus electric current. The mathematical skills such as the solving strategy, unit conversions and area formulae would assist learners in solving EMI problems.

Using these ideas when teaching the topic would provide me with an opportunity to link their prior knowledge with the new knowledge they were learning. This would also give me the opportunity to assess their understanding of these ideas and to redress any misconceptions that they still held regarding them.

Sixth prompt

(Other factors that influence the teaching of these ideas)

This prompt focuses on linking scientific knowledge that they have learned about the topic with the devices that they encounter in their everyday experience which use the process of EMI. Exposing learners to devices such as microphones, tape and disk recorders, as well as credit card swiping machines and encouraging them to describe how they work help them to better understand the scientific principles behind their functioning. This prompt also focused on exposing learners to laboratory apparatus such as the galvanometers, coils and solenoids that are used in *electromagnetism*. Working with such apparatus assists learners to further develop their conceptual understanding of the topic since this topic is not an obvious part of their everyday life. This gives them the opportunity to understand how these apparatus work and learn how to differentiate between a coil and a solenoid for instance.

Seventh prompt

(Teaching procedures – and reasons for using these to engage with these ideas)

This prompt looks at the tactical actions that I chose to enhance different aspects of learning. The teaching procedures ranged from practical activity, group-work, class discussions, question-and-answer method and explanation. The use of a practical activity in the first big idea was meant to afford the learners the opportunity to observe the phenomenon of EMI and to expose them to the apparatus that are used in *electromagnetism*. During this activity, learners worked in groups to observe and predict the outcomes of the activity. Group-work afforded them the opportunity to share ideas as well as to learn to respect and appreciate other people's opinions.

Class discussions were used to probe learners' thinking, evaluate their understanding and summarise the main points of the lessons. These discussions included the question-and-answer method to determine whether their views were in line with the scientific ideas and to link new knowledge with their existing ideas. Diagrams were used to illustrate phenomena and concepts which required further clarification so that learners could better understand these phenomena and/or concepts.

Thus, in as much as the purpose of teaching this topic was to help learners develop a deep conceptual understanding of the topic of EMI, other aspects of learning as required by the curriculum had to be observed. The National Curriculum Statement expects teachers to provide learners with the opportunity to develop process skills such as observing, recording and interpreting information, planning and conducting investigation, and communicating science information. These skills are important in ensuring that learners develop a deeper understanding of the topic.

Eighth prompt
(Specific ways of ascertaining learners' understanding or confusion around these ideas)

This prompt looks at ways that I could employ to assess learner understanding or confusion. These included class and home activities that could be given to learners to evaluate their understanding of the topic, affording them time to ask questions during lessons, and asking them questions that would require them to reveal their understanding or confusion about the topic. A test which covered the whole scope of the topic on EMI was also given to the learners after I had completed teaching the topic. This test was meant to assess their understanding of the topic as well as to allow me to reflect on my teaching of the topic.

The planning of the activities was done in such a way that they met the criteria set by the Department of Education. Past examination papers and various textbooks were used to check questions that related to the topic of EMI. The selection of the questions to be included in these activities was done in such a way that it catered for both procedural knowledge and conceptual knowledge. The decision to include questions that promoted procedural knowledge was taken because I realised that this kind of knowledge was also assessed in the past examination papers and leaving out such questions would disadvantage my learners when exposed to such examinations. Some of these questions were however adapted to ensure that they also promoted conceptual understanding.

5.2.3 Conclusion of the CoRe

The Rollnick *et al.'s* model (2008) was used to trace the elements of teacher knowledge from the CoRe that could have contributed to the development of my PCK. Each element of the model is outlined using the discussion made above as well as the overview of the CoRe. The outline begins with the manifestations as these feed into the domains of teacher knowledge and thus PCK.

Curricular saliency

The CoRe consisted of subject matter knowledge that I intended to teach the learners so that they can better understand the topic. The first prompt of the CoRe included knowledge that I intended my learners to learn about this topic at this particular grade level. The first prompt also included some knowledge that is implicitly covered in the grade 11 curriculum such as the magnetic force and Lenz's law concepts. Their inclusion in the CoRe was meant to assist learners to better understand the topic as these are fundamental in understanding the whole process of EMI.

The third prompt contained knowledge that I intended to withhold from the learners when teaching a particular big idea. This knowledge would be presented to the learners once they have understood the big idea they were supposed to learn before being introduced to this new knowledge. The reason to withhold such information to learners was done in order to avoid distracting or confusing learners from learning the knowledge they were supposed to learn at that particular time and to ensure that their conceptual development progresses without any unnecessary disruptions.

The big ideas were sequenced in such a way that learners' conceptual development would take place gradually. The big ideas were arranged sequentially so as to link what learners have learned in the previous big idea with the current knowledge they were learning and eventually with the subsequent big ideas. This knowledge was also linked with learners' prior knowledge in the third prompt as well as contextual knowledge that linked the topic of EMI with what learners experienced in their everyday life which was discussed in the second prompt.

Thus, the development of my curricular saliency was evidenced by several aspects of teacher knowledge. The first aspect of teacher knowledge was shown by the way I chose what to teach and what to exclude at various stages of teaching the topic. The second aspect was shown by the way I sequenced the big ideas so that learners could learn the topic in a logical order. The third aspect of teacher knowledge was evidenced by the way I linked learners' prior knowledge and contextual knowledge with the topic of EMI.

Teaching strategies

The seventh prompt of the CoRe revealed the teaching strategies that I intended to use when teaching the topic. These included the use of practical activities, group-work strategy, class discussions, and question-and-answer method to promote different aspects of learning. The CoRe revealed another teaching strategy that I intended to employ to explain certain concepts of EMI. With this strategy, I intended to use diagrams to explain the concept of magnetic flux, the existence of two opposing magnetic fields when the magnet is moved relative to the conductor and a method of determining the directions of the changing magnetic field, induced current and magnetic field induced by the current.

The fourth prompt of the CoRe revealed another strategy that I intended to use when teaching the learners how to solve EMI problems. These problem-solving strategies were included in the topic because I realised from the previous topics that my learners lacked some basic skills of solving problems involving calculations. Based on their previous challenges, I decided that I would incorporate the strategy of assisting learners in learning to read the problems carefully in order to identify the relevant equation based on the data provided. I also included some of the mathematical skills that I felt learners would require in solving the EMI problems. These involved unit conversions and area formulae.

These strategies were selected based on the knowledge that I had about the topic, the learners as well as the context from which this topic would be taught. The choice of the strategies discussed in the seventh prompt was based on the knowledge that I had developed when learning the content of EMI and what would work for my learners to

develop conceptual understanding of the topic. The problem-solving strategies were based on learners' challenges that needed to be addressed in order for them to understand the topic as well as to improve on other skills that they were still lacking from the previous topics.

Subject matter representations

The CoRe revealed the subject matter representations that I intended to use when presenting the topic. These included textual and visual representations. Textual representations involved textbooks from which some of the knowledge would have to be retrieved such as definitions the learners would have to learn, diagrams that depicted some of the devices that are used in EMI and the equations that they would need in order to solve EMI problems. The visual representations involved the diagrams that I copied on the transparencies which represented devices such as the microphone and the card swiping machine. The laboratory equipment that would be used in practical activities also represented subject matter representations as these would be used to better explain the topic.

Assessment

The eighth prompt of the CoRe revealed the assessment strategies that would be used to ascertain learner understanding. These included activities that would be provided to the learners both in class and as take-home activities which required them to engage with what they have learned during instructions. A test would be given to the learners after the topic was completed to assess their understanding of the topic. The activities and the test would involve conceptual and procedural knowledge as most of the examination papers included such knowledge. Learners would also be assessed during the course of instructions. The question-and-answer method would be used to probe their understanding and to ascertain if they were following during class.

Subject matter knowledge

The first prompt of the CoRe revealed the aspects of subject matter knowledge that I intended my learners to learn to better understand the topic on EMI. These included

the concepts, laws, rules, and principles that govern the topic of EMI. Each concept was organised in such a way that it consisted of definition(s), factors that influence its magnitude and directions, and equation(s) with their related units of measurement. These aspects of content knowledge represent the structure and organisation of the topic which Shulman (1987) regards as ways of identifying whether the teacher has expert knowledge of the content to be taught.

General pedagogical knowledge

Several aspects of teacher knowledge explained in the discussion of the CoRe revealed the development of my general pedagogical knowledge regarding the teaching of this topic. These included the teaching strategies that were discussed above; the educational aims of teaching the topic that were discussed in the second prompt of the CoRe, and the awareness of learners' cognitive abilities and social behaviours that I focused on in order to enhance learners' understanding of the topic.

Knowledge of learners

The discussion of the CoRe revealed how I understand my learners' learning challenges. Before I presented this topic to them, I was aware of the potential challenges that they would encounter when I teach them this topic. These challenges included their lack of problem-solving skills, their alternative conceptions regarding the devices that use the process of EMI as well as their cognitive abilities and behaviour. These challenges were picked up in the topics that I taught them prior to this topic. Going into this topic, I was quite aware of some of the misconceptions that learners would likely transfer into this topic from other topics, their lack of prior knowledge regarding the EMI topic and their inability to relate some of the devices that they use in their everyday experiences to the EMI.

Knowledge of Context

The CoRe does not explicitly reveal some of the factors associated with the context through which this topic would be presented, except the curriculum to be covered and the resources that would be used to teach this topic. The curriculum to be covered was

provided by the first prompt whereas some of the resources that would be used to enhance learner understanding of the topic are spread throughout the prompts of the CoRe.

Some of the contextual factors that I considered before teaching the topic included the socio-economic background of the learners and the time available for teaching the topic. Some devices that use the process of EMI were copied onto transparencies to show to the learners as some did not have them in their homes. The time available for teaching this topic was also considered when planning the lessons as the topic was taught during the allocated school hours. Learners were also made aware of the possibility of the afternoon classes taking place to ensure that the topic was completed in the stipulated time.

5.3 The PaP-eR

5.3.1 Introduction

The PaP-eR discusses the salient features which I consider contributed to my understanding of the topic on EMI and hence the development of my PCK. The PaP-eR primarily focuses on how I came to learn and better understand the topic rather than how I taught it. However, discussing how I came to understand the topic, I believe, would in turn have an impact on how I would teach it. This would thus contribute not only on my learning but also on how I teach the topic. The reason I chose to approach this PaP-eR in this manner is because I want to show how I transformed the content knowledge I learned about the topic into knowledge that could be understood by the learners. This approach would thus portray the PCK that I developed during the study.

The PaP-eR focuses on how I came to understand the principles that govern the process of EMI; how I learned to understand the method of determining the directions of induced current, induced magnetic field and changing magnetic field; and how I learned ways of solving EMI problems involving calculations. These features are the ones that really helped me to fully understand the ideas of EMI as once I understood them I was in a position to plan how I would teach the topic to my learners. The PaP-

eR is divided into three sections as follows: (1) learning the principles of EMI, (2) method of determining the direction of induced current, (3) solving EMI problems involving calculations, and (4) conclusion of the PaP-eR.

5.3.2 Learning the principles of EMI

Coming to understand the principles of EMI was a challenge since these principles are not explicitly documented in both the curriculum and the school textbooks. I only came to know of their existence when I was constructing the concept maps and the big ideas of the CoRe. During the constructions of the big ideas, it became clear to me that the whole process of EMI can be better understood by combining the first two big ideas as shown in Figure 5.2 under the discussion of the big ideas above. Understanding the process of EMI was instrumental in learning what I regard as the two principles of EMI.

Learning the whole topic of EMI helped me to realise that the process of EMI can be achieved by generating a changing magnetic field in two ways. Firstly, a changing magnetic field can be achieved by moving the magnet in or out of the area enclosed by a conductor. Secondly, it can be achieved by placing a conductor generating an alternating current nearby another conductor from which an induced current will be produced. These ways of generating a changing magnetic field assisted me in identifying the two principles of EMI that can be used to produce current in a closed conductor. These two principles are represented together in Figure 5.4 below.

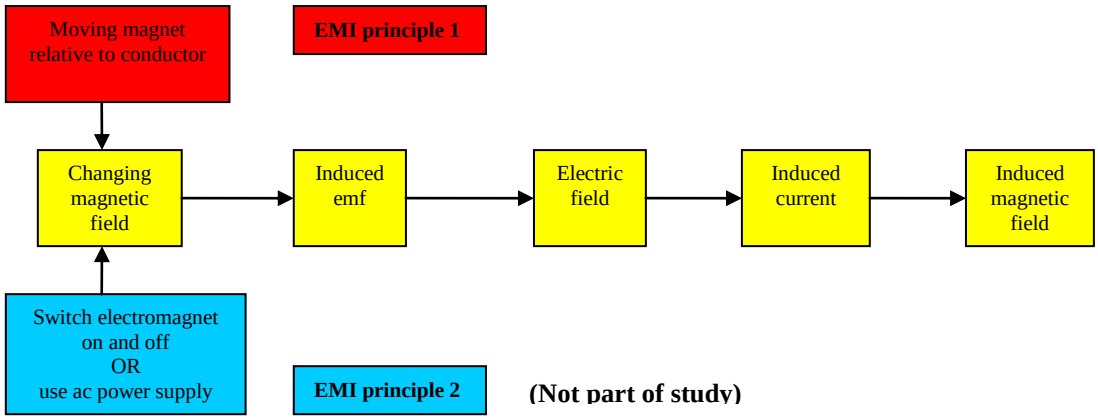
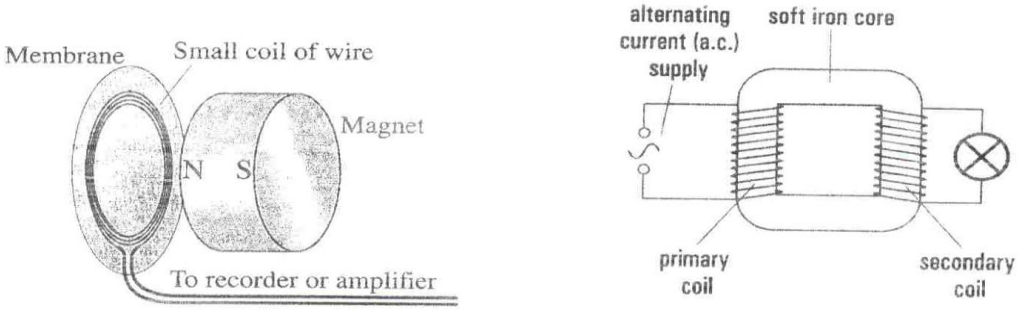


Figure 5.4: The two principles of EMI

The identification of these principles helped me to realise that emf can be generated by other means other than the process discussed in electric circuits where the source of emf is taken, to a large extent, as a battery. Learning these principles made me realised that the battery was not the only source of emf since a changing magnetic field could also induce an emf. The principles also made me aware that this changing magnetic field and hence the process of EMI could be attained in two ways as discussed above.

Identifying these principles made me aware that devices which use the process of EMI use any one of the principles discussed above. A microphone (see Figure 5.5 (a)), as explained by Giancoli (2005), uses the first principle in that sound waves propagated towards the phone causes the membrane attached to the circular wire to vibrate. The vibrating membrane and wire inside a magnetic field provided by the magnet results in this magnetic field changing. The changing magnetic field induces an emf in the conductor which causes the electric field to set up the charged particles in motion. These charged particles are transmitted via the wire as electric signals to the loudspeaker. A transformer (see Figure 5.5 (b)) on the other hand, uses the second principle where the primary coil connected to the ac power supply generates a changing magnetic field that eventually sets up an induced current in the secondary coil (Broster, Carter & James, 2006).



(a) **(b)**

Figure 5.5: Diagrams of a microphone (Giancoli, 2005) and a transformer (Broster *et al.*, 2006)

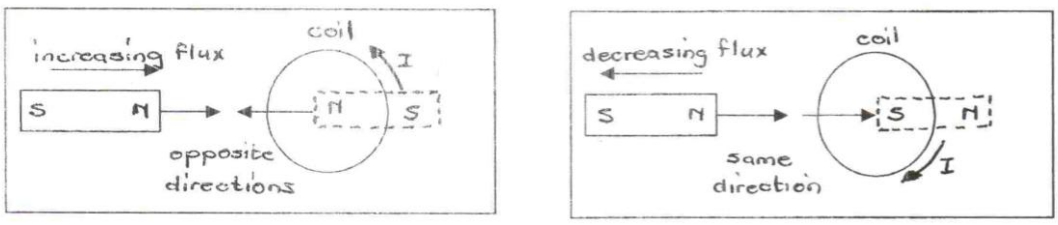
5.3.3 Method of determining the direction of induced current

Mention was made when discussing the fourth prompt of the CoRe above of the potential challenge that my learners could face with regards to misinterpreting the

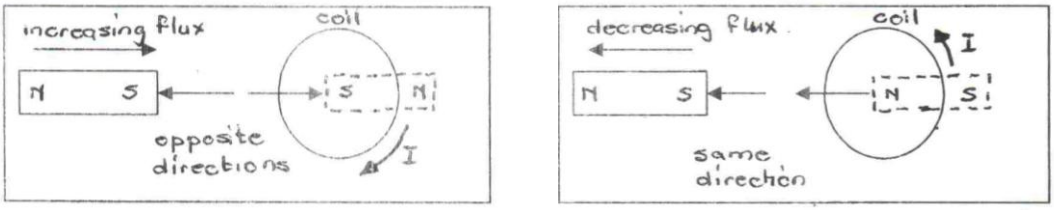
diagrams that are used to indicate the direction of the induced current produced by a changing magnetic field in the conductor. The diagrams shown in Figure 5.3 above work well when the North Pole of the magnet is the one that is considered. However, these predictions fail to hold when the South Pole of the magnet is used to determine the direction of the current.

A better method of determining the direction of induced current in the conductor other than the one used in most school textbooks is the one suggested by Giancoli (2005). This method requires that learners should first establish whether the magnetic field due to the induced current is increasing, decreasing or unchanged. According to this method, a magnetic field due to the induced current is said to be: (1) *increasing* when the two magnetic fields point in the *opposite directions*; (2) *decreasing* when the two fields point in the *same direction*; and (3) *zero* when the field is not changing (not moving). Once the direction of the induced magnetic field is known, then the right-hand rule is used to find the direction of the induced current.

Using this method as suggested somehow poses problems as it is not easy to identify the direction of the induced magnetic field as this field does not have indicated poles like the permanent magnet. Thus, the direction of the permanent magnet that provides the initial magnetic field is used to determine the direction of the induced magnetic field. The magnetic field of the permanent magnet is said to be increasing if the magnet is moved towards the area enclosed by the conductor. The same field is said to be decreasing when the magnet is moved away from the conductor. The diagrams in Figure 5.6 help to depict what is discussed.



(a) (b)



(c) (d)

Figure 5.6: Diagrams showing the method of determining the direction of induced current

The diagrams show how I came to understand this method and how I intended to assist my learners in understanding this method when I taught this section of the topic. These diagrams were designed by me with the help of a diagram that I found in Hendricks *et al.'s* (2009) textbook. The diagrams differ from the Hendricks *et al.'s* diagram in that they have magnets drawn in dotted lines inside the areas enclosed by the conductors. The decision to add the dotted magnets inside the areas enclosed by the conductors was based on the prior knowledge that I had about my learners regarding their difficulty to determine the direction of the magnetic field. Figures 5.6 (a) and (c) represent increasing magnetic fields as the magnets are moving toward the conductors. Figures 5.6 (b) and (d) represent decreasing fields as the magnets are moving away from the conductors. Figures 5.6 (a) and (c) show the magnetic fields opposing each other and Figures 5.6 (b) and (d) show the magnetic fields pointing in the same directions.

The magnets represented by the dotted lines, the directions of the magnetic fields and induced current do not form part of the initial representation of the diagrams. These representations are added to the diagrams as the teacher explains the method of determining the direction of the induced current in each case. The magnets represented by the dotted lines inside the areas enclosed by the conductors are imaginary, drawn to indicate how a magnet that would produce the induced field would position itself if it was real. These imaginary magnets are meant to assist learners to be able to determine the poles and hence direction of the induced magnetic field. It is after the learners had determined the direction of the induced field that they can then apply the right-hand rule to find the direction of the induced current.

The diagrams in Figures 5.6 (a) and (b) were used to show the learners how this method can be applied. The other two diagrams in Figures 5.6 (c) and (d) were used as a class activity to assess learners on what they have been taught. The four diagrams in Figure 5.6 can be used as an expanded opportunity to show learners how Lenz came up with the law he formulated with regards to finding the direction of the induced current. According to this law, the two interacting magnetic fields always oppose each other. The concept of 'opposition' refers to the movement of the magnet and the conductor when they experience a magnetic force caused by the interacting fields. The increasing magnetic field causes the two objects to repel one another and the decreasing magnetic field causes them to attract. In both instances the objects move in opposite directions.

This method enhances conceptual understanding of determining the direction of the induced current in that it reveals all the necessary steps that need to be taken before applying the right-hand rule. This method helps learners to better understand the meanings of the changing magnetic field (increasing or decreasing), the concept of opposing fields, how the Lenz's law was formulated as well as how the magnetic force originates between the magnet and the conductor. Understanding this method also make it easy for the learners to now apply the right-hand rule not only to determine the direction of the induced current but also the directions of the two magnetic fields.

5.3.4 Solving EMI problems involving calculations

Learners who are taking Physical Sciences in grade 11 are subjected to external examination of which the EMI topic is also examined. Most of the past examination papers focus, to a large extent on solving EMI problems involving calculations rather than conceptual knowledge. The information sheets that accompany the examination papers provide two equations that learners are supposed to use to solve such problems. These equations are $\varphi = BA$ and $\varepsilon = -N\Delta\varphi/\Delta t$. These equations are insufficient to solve all the EMI problems since these equations do not cater for the induced current concept that is also asked in such questions. Thus, a third equation $\varepsilon = IR$, derived from Ohm's law is added to assist learners in solving the EMI problems.

Based on previous assessments that I had conducted on these learners regarding problems involving calculations, I anticipated that they were still going to find it difficult to cope with EMI problems which required the same knowledge skills that they still lacked. Their challenges seemed to originate from their inability to apply the necessary solving strategy used to solve problems involving calculations, lack of basic mathematical skills, and their inability to manipulate equations so as to solve the required variable. To address these challenges, I decided that when I teach this section of the topic I would first show the learners how the three equations can be manipulated to extract information that may be helpful in answering other questions related to EMI, discuss the mathematical issues that they need to deal with in order to be able to solve EMI problems and finally revisit the solving strategy that I taught them in the previous topics dealing with problems involving calculations.

The three equations that are provided in the examination papers can be used to define concepts, identify factors influencing such concepts, state Faraday's law and identify related units. For example, magnetic flux can be defined as the product of magnetic field strength and the area enclosed by the conductor using the equation $\varphi = BA$. This equation can also be used to show that the factors influencing the magnitude of the magnetic flux are the strength of the magnetic field and the area enclosed by the conductor. This equation can also be used to derive the other unit of magnetic flux which is $T.m^2$. In the same way, the equation $\varepsilon = -N\Delta\varphi/\Delta t$ can be used to define the induced emf, state the factors influencing its magnitude, determine its direction relative to the change in magnetic flux, state Faraday's law and identify other related units.

These equations can also be manipulated to accommodate other equations that are used in solving EMI problems (see Figure 5.7 below). Learners can be shown that using the change of magnetic field equation $\Delta B = B_f - B_i$ and the change of magnetic flux equation $\Delta\varphi = \varphi_f - \varphi_i$, other equations that relate to the change of magnetic flux, rate of change of magnetic flux, induced emf and induced current can be derived from these equations. Figure 5.7 below shows equations that can be derived from these equations. For example, change of magnetic flux equations are derived from the magnetic flux equation by first inserting the delta signs (Δ) in front of φ and B. This equation is then further explored by substituting ΔB by $B_f - B_i$ in subsequent

equation. The other related equations of the other concepts are derived using the same procedure.

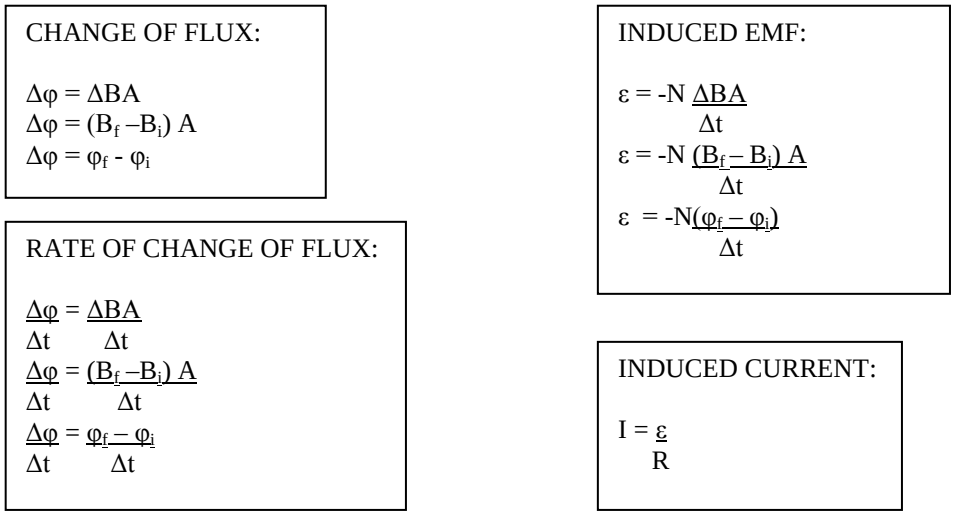


Figure 5.7: Related equations of EMI

The induced current equation can be manipulated further by substituting the induced emf equations in the place of ε. However, this approach is not recommended as learners who are struggling with mathematics may find it difficult to apply such manipulations, e.g. changing $I = \varepsilon/R$ to $I = -N(B_f\text{-}B_i)A/R\Delta t$. A better approach would be to first calculate $\varepsilon = -N(B_f\text{-}B_i)A/\Delta t$ and then substitute the value of ε obtained in $I = \varepsilon/R$.

Once the issue of equations is addressed, learners would then be focused on the mathematical problems that are associated with solving EMI problems. These issues relate to the area formulae required to solve such problems and unit conversions. Learners would be shown that the area formula required when dealing with problems involving solenoids and coils is $A = \pi r^2$ and the one for the rectangular wire is $A = \ell^2$. They would also be shown how $1m^2$ can be converted to 10^4 cm^2. The section on unit conversions would focus on how learners can use the EMI equations to derive other related units. For example, it can be shown that the unit of induced emf, a volt (V), can be written as $1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$ using the equations $\varepsilon = -N\Delta\varphi/\Delta t$ and $\varepsilon = -N\Delta BA/\Delta t$ where N and the negative signs are not considered as they do not have units.

This section would be followed by teaching the solving strategy required to solve problems involving calculations. This section would require learners to work in pairs to first write down all the variables together with their units that are given in the problem provided as well as the variable that needs to be calculated. This would be followed by requiring them to convert any units that are not expressed in their SI system in the data. This step would be followed by identifying the suitable equation and then substituting the variables in the equation. The next step would require them to determine the answer and then insert the SI unit of the variable to be solved next to the numerical value obtained. Learners would then be provided with other problems to ensure that they implemented this strategy when solving problems involving calculations.

5.3.5 Conclusion of the PaP-eR

The PaP-eR reveals aspects of teacher knowledge that were crucial for the development of my PCK regarding the EMI topic. The use of problem-solving strategy to assist my learners in learning how to solve EMI problems and my intention to demonstrate how the direction of the induced current can be determined confirmed that I was developing *teaching strategies* which would be used when presenting the topic. The diagrams depicted in the PaP-eR revealed my intention to use various *subject matter representations* in transforming the content into knowledge comprehensible to the learners.

The development of my *curricular saliency* was confirmed by the way I added the Ohm's law equation to the EMI equations and linking mathematical issues into the topic to enhance learner learning. Mention was also made in the PaP-eR of how I intended to use two of the diagrams as part of a class activity to assess learners when explaining the method of determining the direction of the induced current. The development of my *assessment knowledge* was also confirmed when I indicated that learners would work in pairs when I take them through the problem-solving strategy and that they would be provided with more problems to practice the strategy.

The PaP-eR shows how my *subject matter knowledge* developed as I learned the topic. The PaP-eR indicates how I learned the two principles of EMI and how these

principles can be applied to various devices that use them. Identifying the suitable method of determining the direction of the induced current (suggested by Giancoli) and other EMI equations (excluding $\Delta\varphi = \Delta BA$; $\varepsilon = \Delta\varphi/\Delta t$; and $\varepsilon = I/R$) which are not explicitly stipulated in the content document also confirmed the development of my content knowledge. Designing the diagrams as indicated in Figure 5.6 and manipulating the equations as shown in Figure 5.7 confirmed that *knowledge of learners* was considered when I was preparing to teach the topic.

The development of my *general pedagogical knowledge* was revealed by the teaching strategies that are reflected on the PaP-eR. These teaching strategies include demonstrating how a microphone functions, employing a problem-solving strategy to solve EMI problems, using diagrams to illustrate how to determine the direction of the induced current and explaining the principles of EMI. *Knowledge of the context* was demonstrated by my awareness of the curriculum to be covered, the resources that I intended to use when teaching the topic and the understanding of my learners' learning challenges.

5.4 Overall conclusion

This chapter looked at how the constructions of the CoRe and PaP-eR assisted me in capturing and documenting the development of my PCK regarding the topic on EMI. The overall purpose of constructing the CoRe was to capture those aspects of teacher knowledge which would emerge as evidence of what I learned during the learning of the topic. The construction of the PaP-eR, on the other hand, was meant to illuminate aspects of my teacher knowledge that would inform my teaching when I present this topic to the learners. Thus, the discussion of the CoRe and PaP-eR in this chapter was meant to highlight aspects of my teacher knowledge which are indicative of the nature of PCK that I developed during the study of EMI.

The CoRe assisted in accessing what I understood about the topic as well as in identifying aspects of teacher knowledge that I would require in order to present this topic effectively to the learners. The development of the CoRe was instrumental in assisting me to identify the main ideas of the topic, in sequencing the lessons, identifying potential learners' learning challenges, identifying ways of assessing their

understanding as well as the teaching procedures that I would use to enhance learner understanding. The PaP-eR assisted me in elucidating how I intended to employ various teaching strategies and subject matter representations to address learners' challenges as well as assess their understanding and confusion regarding the topic.

Both the CoRe and PaP-eR were influential in assisting me to learn the topic as well as prepare how I would present the topic to the learners. Through them, I was able to plan the lessons in a sequential order to ensure that learners were able to grasp knowledge progressively. Both the CoRe and PaP-eR were helpful in deciding the resources that I would use and to plan how the classroom would be organised to facilitate instructions. The development of the CoRe and PaP-eR illustrated the importance of considering different aspects of teacher knowledge when transforming the subject matter knowledge. These aspects of teacher knowledge were instrumental in provoking my thinking and assisted me in articulating what I learned during the study.

The Rollnick *et al.'*s model of PCK was used in each case to establish the aspects of teacher knowledge that emerged from the CoRe and PaP-eR. The model was successful in that it assisted me to identify aspects of my knowledge of teaching such as subject matter knowledge, knowledge of learners, general pedagogical knowledge, contextual knowledge, curricular saliency, subject matter representations, teaching strategies and ways of assessing the learner understanding. These aspects of teacher knowledge assisted me in transforming the content that I learned into knowledge for teaching. These aspects of knowledge are the ones that fed into the development of my PCK and are thus representative of the nature of the PCK that I developed.

This chapter looked at how I developed the CoRe and PaP-eR to assist me in capturing and portraying the development of my PCK. The chapter illustrated various aspects of teacher knowledge that emerged as evidence of what I learned and also illustrated how I planned to teach this topic to the learners. Chapter 6 will look at how I apply the knowledge that I have learned to my classroom practice. The chapter will focus on how I taught this topic to the learners, look at those aspects of PCK that assisted me in teaching the topic and also look at those aspects that still need development.

CHAPTER 6

INTEGRATING TEACHER KNOWLEDGE IN THE CLASSROOM

6.1 Introduction

This chapter looks at how my PCK developed while teaching the topic on EMI to the learners in the classroom. The chapter first looks at the various data sources that were analysed regarding instruction delivery of the topic. The chapter then proceeds to discuss how the Rollnick *et al.'s* model of PCK was used to analyse the contents of the lessons presented. This section is followed by data analysis of the various data sources that were used during instruction delivery. The chapter ends with a discussion that focuses on those aspects of teacher knowledge that contributed towards the development of my PCK and those aspects that still require further development.

6.2 Data sources

Most of the data used to analyse my teaching in the classroom was captured from the videotapes of the lessons that I presented on the topic. A total number of four lessons were video-recorded for the purpose of analysing my teaching. These lessons followed the format represented in the lesson plans that I constructed (see Appendix H). The videotaped lessons are recordings of the lessons that focused only on the section of EMI that deals with electric current that is induced by moving the magnet relative to the conductor. A total time of five hours was spent in recording the four lessons over a period of five days.

Opie (2004) warns against videotaping many lessons as these may result in large amounts of data having to be processed and analysed. On the other hand, Loughran *et al.* (2004) suggest that a teacher's PCK may not be articulated clearly within the parameters of one lesson as this notion requires an extended period of time to unfold. Thus, the choice of videotaping four lessons rather than one or two was meant to broaden the base from which I would gather sufficient evidence regarding the development of my PCK.

To help manage the data that was gathered from the videotapes, a decision was taken by my supervisor and I that only the data that was relevant in answering my research questions would be transcribed from them. The videotaped lessons were viewed over and over again to identify sections of the lessons that contained relevant data. Each videotape was initially viewed with the intention to break it down into time slots representing each scenario that took place during the lesson. These scenarios were then classified or grouped in terms of teacher knowledge that they represented.

Other data sources such as the lesson plans, reflective journal and assessment tasks (worksheets and post test) were also used to analyse my teaching. Their use in the analysis varied depending on how they were required to assist in supporting the evidence that was gathered. In some instances, these data sources were used as tools for observing and reflecting on the teaching that took place. In other instances, they were consulted either for verification purposes or as means for triangulating the findings that emerged from the videotapes.

6.3 Analytical framework

In chapter 2 of this study, mention was made that the Rollnick *et al.'s* model of PCK classifies teacher knowledge into two broad categories called the domains and manifestations. The domains are knowledge of the subject matter; knowledge of learners; knowledge of context and general pedagogical knowledge, which when amalgamated produce PCK. The manifestations are any visible aspects of teacher knowledge which can be observed during classroom practice. For the purpose of this study, these manifestations are curricular saliency, topic-specific instructional strategies, subject matter representations and assessment as suggested by the Rollnick *et al.*'s model.

The view that the domains produce PCK and that the manifestations are the products of the domains imply that the domains can be viewed as the inputs of PCK and the manifestations as the outputs of PCK. This view suggests that the Rollnick *et al.*'s model can be viewed as proceeding from the domains through to PCK and finally to the manifestations as shown in Figure 6.1 by the red arrow lines.

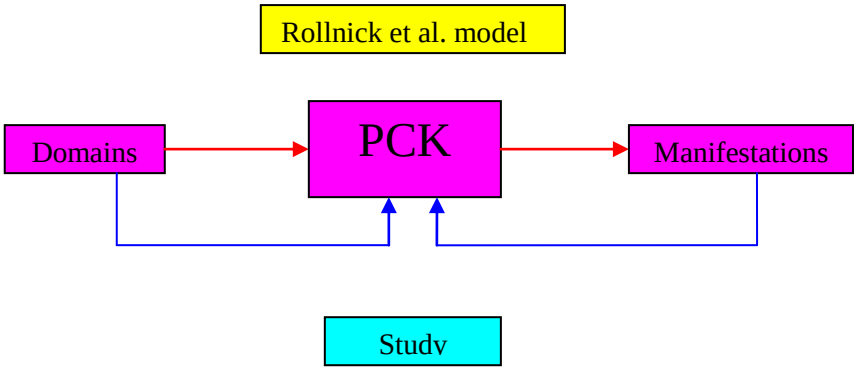


Figure 6.1: Representation of the Rollnick *et al.'s* model of PCK according to the analytical framework of this study

In this study, the Rollnick *et al.*'s model of PCK is applied differently for the purpose of analysing my teaching in the classroom. The blue arrow lines in Figure 6.1 depict the approach I followed in analysing my teaching. The videotaped lessons were first analysed using aspects of teacher knowledge which constitute manifestations. This was then followed by analysing aspects of teacher knowledge that represent the domains. The results of both the domains and manifestations were then analysed together to construct an integrated knowledge of teaching which eventually articulated my PCK.

6.4 Data analysis

The analysis commences by discussing the four categories of manifestations mentioned above that emerged from the data. This is followed by the two domains which also emerged during analysis, namely SMK and knowledge of learners. These two domains are paramount in this study since my research questions focus on knowledge of the subject matter and on teaching, which is learner-centred.

6.4.1 Manifestations

Curricular saliency

Geddis *et al.* (1993) regard curricular saliency as that aspect of teacher knowledge that enables the teacher to accurately judge the depth to which the curriculum should be covered within a prescribed period of time. Curricular saliency is informed by the

amount of content to be taught, the knowledge of learners and the educational purposes of teaching such a topic (Geddis *et al.*, 1993). Curricular saliency determines what needs to be included or excluded in the topic and explains why certain things are explained in details and why some are not detailed (Rollnick *et al.*, 2008).

A closer inspection of the grade 11 curriculum on EMI (Appendix F) reveals that the curriculum emphasises the teaching of the EMI process, Faraday's law, Right Hand Rule and the use of equations to solve EMI problems. The curriculum does not however explicitly stipulate how the concepts used in EMI should be defined or conceptualised. What the curriculum does reveal is how Faraday's law should be stated and how the Right Hand Rule should be used to determine the directions of the induced current and its associated magnetic field. The curriculum further shows the quantities for which the two equations ($\varepsilon = -N\Delta\Phi/\Delta t$ and $\Phi = BA$) should be used in calculations.

Geddis *et al.* (1993) acknowledge that curriculum documents seldom articulate curricular saliency explicitly and that this aspect of teacher knowledge therefore remains a function of a teacher to undertake in ensuring that the topic is taught in the best possible way. Thus, the lessons that I presented focused both on the content that was explicitly and implicitly stated in the curriculum which I felt was valuable in enhancing learner understanding of the topic. The paragraphs that follow discuss how I addressed the limitations of the curriculum to ensure that the topic was transformed comprehensively to the learners.

The following excerpt from the Physical Sciences Content document proposes how the EMI process should be taught. The excerpt reads: "Use words and pictures to describe in words and pictures what happens when a bar magnet is pushed into or pulled out of a solenoid connected to an ammeter" (DoE, 2006, p. 66). The extract suggests the use of illustrations (words and pictures) to explain the process. Such an approach was going to be ineffective for my learners since they had no prior knowledge of the EMI phenomenon and a majority of them had difficulty visualising scenarios from the pictures. In the lesson that I presented on the EMI process, this disparity was addressed by first engaging learners in a practical activity which allowed them to observe the phenomenon firsthand before the approach of 'words and

pictures' could be used. Figure 6.2 shows learners working in a group trying to develop their own knowledge of the EMI process.



Figure 6.2: Learners working in a group

The use of words such as *'use'*, *'state'*, and *'calculate'* in the curriculum document seems to suggest that the curriculum promotes procedural learning rather than conceptual understanding. In the lessons that I presented I focused on the conceptualisations of definitions, rules and laws before learners could apply them in other situations. For example, learners were encouraged to define concepts such as induced current and induced emf in terms of a changing magnetic field to distinguish these from the very same concepts used in electric circuits. The following excerpt from a video-recorded lesson depicts how I intended my learners to distinguish between the electric current set up in electric circuits and the induced current:

> Teacher: … You need to take note of the difference between the two electric currents. The one that is produced by the electric circuits is due to the emf provided by the battery. Whereas this one [induced current] is due to something else, that is the magnetic field. Thus, this current [induced current] is simply produced by the changing magnetic field.

This excerpt shows that in as much as electricity and magnetism are related in terms of both producing electric current, they somehow differ in terms of the origin of their currents.

The curriculum further proposes that the equations ($\varepsilon = -N\Delta\Phi/\Delta t$ and $\Phi = BA$) should be used to calculate EMI problems involving induced emf and induced current. The two equations however do not contain induced current as one of the quantities. Thus, to help my learners connect the induced current concept to the two equations I re-introduced Ohm's law equation ($V = IR$). The following excerpt from the video-

recorded lesson shows how I went about linking Ohm's law equation to these equations:

> Teacher: … the equation that we really use here is the Ohm's law equation. Do you still remember it? By the way what is Ohm's law equation? Who can give me the formula for Ohm's law?
>
> Learner 1: R is equal to I over V[R = I/V].
>
> Teacher: No. R is equal to?
>
> Learner 2: V over I [R = V/I].
>
> Teacher: V over I. Do you still remember that?
>
> Learners: Yes.
>
> Teacher: Now in this case we are not working with potential difference [V] but we are working specifically with what we call induced emf (ε), okay! So instead of potential difference here [pointing on V in R = V/I], in our equation we are going to write 'e' [ε] over I.

By indicating to the learners that Ohm's law equation can be written as $\varepsilon = IR$ and showing that this equation was related to $\varepsilon = -N\Delta\Phi/\Delta t$, I was able to show my learners that the induced current could be calculated using these equations.

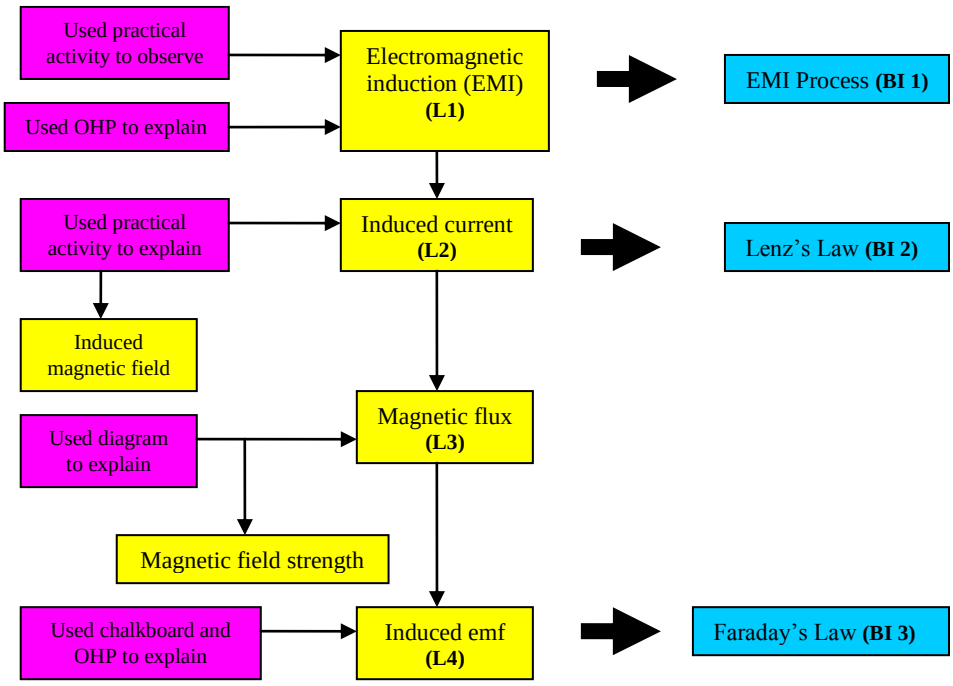
My curricular saliency was also revealed by the way I considered what was implicitly stated in the curriculum which I felt would benefit the conceptual development of my learners. As already mentioned herein, somehow hidden in the curriculum were the *magnetic field strength* concept and the *Lenz's law* which I felt learners should also learn to better understand the topic. The magnetic field strength concept was included after I had noticed that learners were expected to determine it in calculations involving EMI problems. The magnetic flux equation was used to conceptualise the concept by showing learners that this equation could be rewritten as $B = \Phi/A$. Based on this equation, magnetic field strength was then defined as '*the total number of magnetic field (flux) lines per unit area*'.

It is somehow disturbing to observe that Lenz's law is omitted in the "Core knowledge and Concept" section of the Physical Sciences content document and yet a statement is written in the "comments and links" section of the same document stating that: "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)" (DoE, 2006, p. 66). This

statement reveals the importance of Lenz's law and yet the "Core knowledge and Concept" section of the curriculum does not explicitly stipulate the law as a fundamental concept that learners should learn to better understand the method of determining the direction of the induced current. Lenz's law was discussed in the lessons to help learners understand that there are two magnetic fields (changing magnetic field and induced magnetic field) involved in the EMI process and also that it is the magnetic field induced by the current that ultimately determines the direction of the induced current and not the changing magnetic field producing the current.

Topic-specific instructional strategies

Rollnick *et al.* (2008) refers to topic-specific instructional strategy as a broader teaching approach used by the teacher to facilitate instruction in a direction that promotes learning. The overall instructional strategy used in this study was informed by the knowledge of the logical structure of the content that I had learned, the knowledge of the learners which I had before instruction and the lesson objectives of the topic. The strategy is drawn from the lessons that I presented and is represented by a flow diagram depicted in Figure 6.3 below.



Note: BI 1 – BI 3 refers to big ideas 1 to 3; L1 –L4 refers to lessons 1 to 4

Figure 6.3: Representation of the overall instructional strategy

The overall instructional strategy shows how knowledge of the content followed a particular sequence from the first lesson (represented by L1) all through to the last lesson (L4). Lesson 1 focused on the introduction of the EMI process and lesson 2 on the *induced current* and *induced magnetic field* concepts. Lesson 3 focused on the *[changing] magnetic flux* and *magnetic field strength* concepts and lesson 4 on the *induced emf* concept.

The sequence in which the lessons progressed was influenced by the instructional strategy employed in lesson 1. Learners were engaged in a practical activity that required them to observe the EMI process. The reason for engaging learners in this kind of activity was to first familiarise them with the process of EMI and then use this process to indicate the direction which the subsequent lessons would follow. Figure 6.4 shows a concept map presented earlier on which depicts the EMI process established in lesson 1.

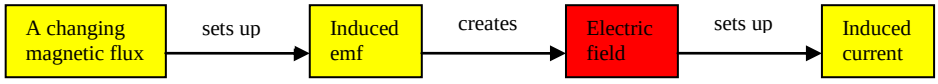


Figure 6.4: A concept map representing an EMI process

This map was used in lesson 3 to indicate to the learners how the topic was unfolding into a series of sequential lessons. The following excerpt from the video-recorded lesson provided below confirms the sequence followed in teaching the topic.

> Teacher: … so far we've covered the **induced current**. We are not going to stick [focus] that much on **electric fields**. [Actually] we are not going to discuss them simply because electric fields are discussed under electric circuits and we've already done that. So what we need to focus on now is the **induced emf** as well as the magnetic fields or what we call **magnetic flux**.

This excerpt extracted from lesson 3 shows how the lessons progressed from lesson 1 to lesson 2 and how they would progress from lesson 3 to lesson 4. The excerpt also indicates why the section on electric fields was left out.

The three big ideas that I formulated in the CoRe constructed earlier also emerged in the lessons that I taught. After I had finished teaching the topic on EMI, I was worried that I really did not mentioned to the learners the big ideas (represented by BI 1 - BI 3

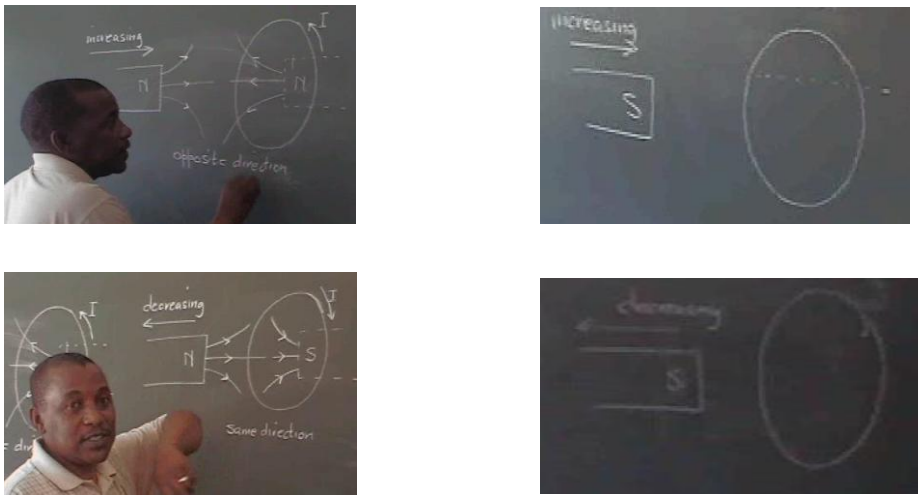
in Figure 6.3) of the topic. However, as I was analysing the data on the lessons presented it dawned on me that this problem was actually addressed during instruction. The mere fact that the EMI process, Lenz's law and Faraday's law were discussed in detail during instruction confirms that these ideas were brought up to the attention of the learners. My initial concern emanated from the fact that I did not use the 'big idea' concept per se when presenting the lessons but rather implicitly discussed these ideas as important parts of the topic which learners had to understand.

The first big idea was explored more than the other two big ideas. In the first lesson it was observed and discussed as the EMI process and in subsequent lessons used to introduce other EMI concepts. The second big idea, which revolves around Lenz's law, was discussed in detail when discussing the *induced current* and *induced magnetic field* concepts. The third big idea, which emphasises Faraday's law, was discussed using the Faraday's law equation. This idea was explored first by conceptualising the Faraday's law, followed by showing learners how this law is used to derive the Faraday's law equation and eventually how this equation is used to solve EMI problems. This suggests that both conceptual and procedural aspects of learning were addressed in the third big idea.

Several other teaching strategies emerged from the presentations of these lessons. These strategies include the *problem-first* strategy, *supervised in-class* strategy and *practice-problems* strategy (Geddis *et al.*, 1993). The *problem-first strategy* was used in the first lesson as a means that would provide learners with the opportunity to observe the EMI phenomenon before the concept could be discussed in detail as learners lacked prior knowledge of the concept. The *problem-first strategy* was also used in the second lesson to assist learners in identifying the factors that influenced the magnitude of the induced current before these factors could be discussed in details. The use of this strategy in the lessons was meant to provide learners with the basis for conceptualising the content.

The *supervised in-class strategy* was used in lessons 2 and 4. In lesson 2, the strategy was employed after I had taught the learners the method used to determine the directions of the induced current and its induced magnetic field. Here, the strategy was used with a purpose of establishing whether learners understood this method and

if not, to establish the origins of their learning difficulties. Figure 6.5(a) shows the diagrams that I drew on the chalkboard as I explained the method and Figure 6.5(b) the diagrams that learners used to practice the method.



(a) **(b)**

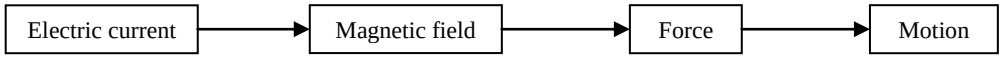
Figure 6.5: Diagrams showing the directions of induced current and its magnetic field

In lesson 4, the *supervised in-class strategy* was used with two purposes in mind, namely (i) to provide learners the opportunity to derive other equations related to the equations that I had already taught them, (ii) to establish the origins of their learning difficulties regarding solving EMI problems so that these could be addressed. The *practice-problems strategy* was employed in three of the four lessons that I taught. This strategy was used with the intention of assessing learner understanding of the content that they had learned.

Subject matter representations

Various ways of representing subject matter emerged from the lessons that were presented on the topic. These forms of subject matter representations included amongst others diagrams, laboratory apparatus, concept maps, formulae, examples, illustrations and a few analogies. These ways of representing subject matter were used to 'transform the subject matter into knowledge accessible to the learners' (Geddis *et al.*, 1993). These representations assisted in explaining, illustrating and demonstrating the phenomena I was trying to teach.

Concept maps were used for various purposes during lesson presentations. They were used either to link learners' prior knowledge with the new knowledge that they had to learn or to summarise the work covered in a particular lesson. For example, in the first lesson where EMI was first introduced, a concept map was drawn on the chalkboard with the participation of learners as follows:



This concept map illustrates knowledge of *electromagnetism* that learners brought with them prior to the teaching of the topic on EMI. The construction of this concept map reveals two big ideas that they had learned previously, namely that (i) electric current can produce magnetic effects and (ii) electrical energy can produce kinetic energy. These big ideas were used to link their prior knowledge with new knowledge, namely that (i) magnetic effects can result in electricity and (ii) kinetic energy can produce electrical energy.

Diagrams were used to explain or illustrate new concepts, to correct misconceptions or reinforce what was already explained. These diagrams were either copied on the OHP transparencies for easy access or drawn on the chalkboard as I explained the content. The diagram shown in Figure 6.6 was used to explain to the learners how an induced current creates its own magnetic field.

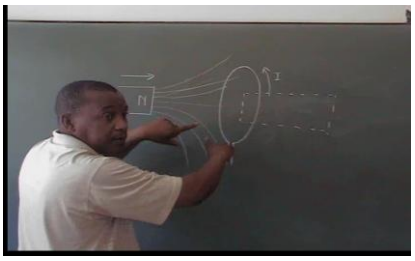


Figure 6.6: A diagram showing how an induced current creates its own field

The following excerpt from the video-recorded lesson shows how I used the diagram to explain how an induced magnetic field is created by a changing magnetic field.

> Teacher: …so what happens is when you move your magnet towards the coil that [changing] magnetic field is going to induce the current here [pointing the coil]. … . and when that current is induced it is going to produce its own magnetic field here [pointing the area enclosed by the coil]. … so when you bring this [magnet towards coil] it's like you have two bar magnets. …I'm going to draw it [second magnet] in dotted lines because you really don't

> have a magnet here. …this one [second magnet] has its own magnetic field caused by an induced current.

This excerpt shows how the diagram was influential in assisting me to explain the setting up of the induced magnetic field in the area enclosed by the coil. The excerpt reveals how a changing magnetic field induces a current in the coil and how this induced current in turn produces its own magnetic field. These two statements are nothing but two propositions which ultimately lead to the formulation of the second big idea. Thus, by explaining how the induced current created its own magnetic field I was also extending the EMI process to accommodate the induced magnetic field. This means that I was implicitly connecting the first big idea (EMI process) to the second big idea (Lenz's law).

The excerpt and the diagram also show the dilemmas associated with the use of diagrams. In the diagram I used dotted lines to draw a bar magnet in the area enclosed by the coil. Such a magnet does not exist but is placed there to try and explain to the learners how the directions of the induced magnetic field and induced current could be determined. Using such an illustration could lead some learners to believe that such a magnet exists and this could cause them to develop misconceptions about the topic. Lampert (1985) in Geddis *et al.* (1993) acknowledges that such dilemmas exist where concrete examples may distort the phenomena they are trying to illustrate and that such dilemmas cannot be eradicated completely. However, he recommends that they should be managed in such a way that they do not disrupt the very same learning they are supposed to enhance. Thus, throughout the lesson I kept reminding the learners that such a magnet does not exist but is put there to assist them to understand the method of determining the directions of induced current and its magnetic field.

Laboratory apparatus were used to illustrate certain concepts or phenomena. The apparatus used in the lessons included galvanometers, solenoids, conducting wires and bar magnets. In the first lesson the use of apparatus was two-fold, namely (i) to give learners the opportunity to use some of the apparatus that are used in EMI and (ii) to allow learners to observe the EMI phenomena firsthand. In the second lesson the use of apparatus was meant to assist learners in investigating the factors that

influenced the magnitude of the induced current. In subsequent lessons, the apparatus were used to reinforce knowledge that has already been explained.

Figure 6.7 shows how one of the groups went about investigating the EMI phenomenon.



Figure 6.7: Learners in a group performing an investigation

The following excerpt from the video-recorded lesson shows how the apparatus assisted learners to develop a deep understanding of the EMI phenomenon.

> Learner 1: Bheka, bheka! Nengiyifaka iya ngapha. Nengiyimisa iba ku-zero. Nengiyi khipha iya le! [Look,look! When I insert it (the magnet), it (the needle) goes this way. When I let it (the magnet) stands still, it (the needle) reads zero. When I remove it (the magnet), it (the needle) goes the other way!]
>
> Members: Iya! [Yes!]

This excerpt shows how members of the group came to understand the process of EMI. By observing the process in a practical activity they came to understand that an electric current could be produced by changing a magnetic field.

The following excerpt illustrates what happened during one of the practical activities that were conducted by the learners using apparatus.

> Teacher: No, just use one [magnet]. We don't have time to test what you are not supposed to test! We've got time to test what you are supposed to test!

This excerpt shows how I had to stop some of the learners who went overboard to perform experiments which they were not supposed to perform. Giving learners the opportunity to work with apparatus proved to be an invaluable experience for them. Learners were fascinated by the results which confirmed what they were learning and were actively involved in the discussions that followed. Not only did the apparatus

afford them the opportunity to learn but the apparatus also stimulated their interest which prompted them to try things they were not supposed to do.

Assessment

This section discusses how learners responded to the questions that were asked in the test (Appendix J) that they wrote after they had completed the topic on EMI. The test covered sections on current induced by moving a magnet relative to the coil and mutual induction. The discussion that follows focuses on the former section since mutual induction does not form part of this study. Thus questions 1.5; 2.4; 2.5; 3.5 and 8 do not form part of this analysis as they focus on mutual induction. Question 4 is also excluded in the analysis because it focuses mainly on practical investigation skills.

Table 6.1 below shows how the 20 learners performed in the test. The test performance scores ranged from 18% to 81%. Six learners (30%) got scores of more than 50%, 9 learners (45%) scored above 30% but less than 50% and 5 learners (25%) got scores below 30% which is the minimum pass requirement in the subject.

Table 6.1: Learner performance on EMI test

Level Descriptors	Percentage	No. of learners
7	80 – 100	1
6	70 – 79	1
5	60 – 69	1
4	50 – 59	3
3	40 – 49	5
2	30 – 39	4
1	0 – 29	5
Total no. written		20

These results suggest that 75% of the learners who sat for the test managed to pass the test according to the minimum pass requirements (which is 30%) and only 25% failed the test.

The analysis also show that in as much as a significant number of learners have conceptualised the process of EMI, a substantial number of them were still unable to

connect this concept to its practical application. Only 4 out of 20 learners were marked totally correct, another 4 were marked partially correct and the remaining 12 were marked totally incorrect in a question where they were supposed to use the EMI process to explain how a microphone works. The following excerpts show how some of the learners responded to this question:

> Learner 1: The emf is induced by a changing magnetic flux to produce an induced current so that the current will flow and so the microphone gets to work from then.
>
> Learner 2: The membrane vibrates and touches the coil and it [coil] also vibrates and also moves towards the magnet everytime the membrane vibrates and current is produced and sound is heard.
>
> Learner 3: When the sound enters the microphone, the sound causes [the] membrane to vibrate. When the membrane vibrates it causes the small coil to move back and towards the magnet creating a changing magnetic flux that sets up an induced emf that produces an induced current [in the coil].

Learner 1 shows a deep understanding of the process of EMI but does not know how to apply it in the workings of the microphone. Learner 2 fairly understands the workings of the microphone but does not indicate how the process of EMI is involved in its workings. The two learners are therefore unable to connect their conceptual knowledge with application. On the other hand, learner 3 shows a deep understanding of the EMI process and is able to connect it to its practical application.

Learners' understanding of the EMI concepts was further analysed by focusing on the questions that required them to identify factors that influenced the vector nature of concepts. Questions 5.2 and 7.2 tested learners' understanding of the factors influencing the magnitude of induced current and magnetic flux respectively. Seven out of 20 learners were marked totally correct, 9 were marked partially correct and 4 were marked totally incorrect in question 5.2. Seven out of 20 learners were marked totally correct, 7 partially correct and 6 totally incorrect in question 7.2. The 7 learners who were marked partially correct were as a result of them obtaining one correct answer instead of two in question 7.2. The 9 learners who were marked partially correct in question 5.2 was as a result of them providing one instead of two correct answers as well as providing two answers which were both partially correct.

The following excerpts show how some learners responded to question 5.2:

> Learner 1: (i) the speed of magnet relative to the coil;

(ii) the number of turns in the coil.

Learner 2: (i) change the direction of current;
(ii) increase the number of turns in the coil.

Learner 3: (i) increasing the number of turns in the coil;
(ii) adding two or more magnets.

Learner 1 was marked partially correct because he was able to identify the factors that influence the magnitude of the induced current but was unable to indicate how its strength could be increased. Learner 2 was marked partially correct because her first answer was totally incorrect and her second totally correct in that not only did she identify the factor but was also aware that it should be increased. It could be argued that: (i) learner 1 did not fully understand the question although he knew the factors that influenced the magnitude of the current, (ii) learner 2 fully understood the question but did not know all the factors to be considered, and (iii) learner 3 understood the question fully and also knew all the factors concerned.

Table 6.2 shows all the questions that involved calculations and how learners responded to these questions.

Table 6.2: Learners' performances on calculations

Questions	Totally correct	Partially correct	Totally incorrect
3.2	**9** (45%)	**0** (0%)	**11** (55%)
3.3	**9** (45%)	**0** (0%)	**11** (55%)
7.3	**8** (40%)	**10** (50%)	**2** (10%)
7.4	**1** (5%)	**1** (5%)	**18** (90%)
7.5	**3** (15%)	**16** (80%)	**1** (5%)
7.6	**2** (10%)	**4** (20%)	**14** (70%)

Questions 3.2 and 3.3 were multiple choice questions where learners had to choose the correct answer from four possible answers that were provided for each question. However, learners had to do some calculations using relevant formulae to determine the correct answer. Nine out of 20 learners got the answers correctly for each question. In these questions it could not be decided whether learners got the answers incorrectly because they chose incorrect formulae or their problems were as a result of their mathematical learning difficulties.

Questions 7.3 to 7.6 involved questions that required learners to identify the relevant formulae and substitute in the formulae to obtain the correct answers. A total of 18 out

of 20 learners could not identify the formula [$\Delta\Phi/\Delta t$ or $(Bf - Bi)A/\Delta t$] for the *'rate of change of flux'* they were supposed to use in question 7.4 to solve the problem. This gloomy performance could be attributed to their inability to distinguish between the 'change of flux' and 'rate of change of flux'. Figure 6.8 shows responses which were given by two learners.

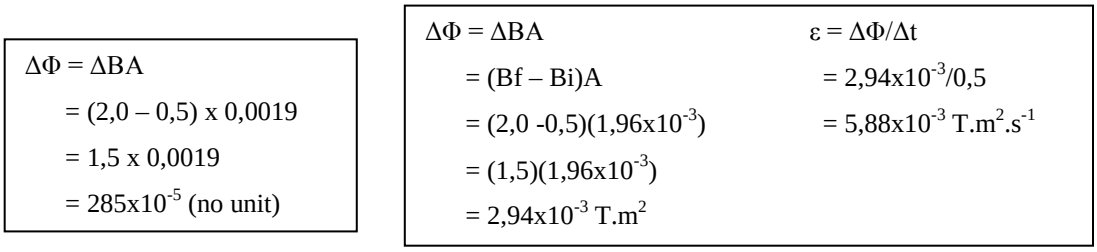


Figure 6.8: Responses of learners 1 and 2 respectively

Twelve (including learner 1) of the 18 learners marked totally incorrect were marked as such because no mark was allocated for calculating the change in flux. Learner 2 first calculated the change in flux and went further to calculate the rate of change of flux as required. Learners' inability to distinguish between the two concepts could stem from the 'rate' concept itself. The concept of 'rate' seem to be a serious concern with my learners as every time I discuss it with them they seem to understand it but when they are supposed to apply it they are unable to do so.

A total of 14 out of 20 learners were marked totally incorrect in question 7.6. Of the 14 learners, only 5 learners did identify the correct formula [$R = \varepsilon / I$] but wrote it incorrectly when determining the current. The responses of these 5 learners reveal their inability to determine the subject of the formula when solving calculations. The other learners either used the formula [$I = Q/t$, which was inapplicable in this case] which was provided in the information sheet for calculating the current or other formulae that were inappropriate for solving the problem.

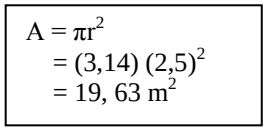
Learners' inability to solve question 7.6 could stem from their inability to identify the variable associated with this question which was calculated in the preceding question 7.5. Question 7.6 required the learners to calculate the induced current when the resistance in the coil was 36Ω. This suggests that learners were supposed to look for another quantity which they could use to solve this problem as the two formulae [$R = V/I$ and $I = Q/t$] applicable in determining the induced current had three quantities

each. For them to solve this question they had to realise that the induced emf calculated in question 7.5 was supposed to be used for V (voltage) in R = V/I.

Question 7.3 is the question involving calculations which was better answered by the learners. Eight out of 20 learners were marked totally correct, 10 partially correct and only 2 totally incorrect. Only 1 of the 10 learners marked partially correct managed to identify the required formula and proceeded to the second step of the solution. Only 3 out of 20 learners were marked totally correct and only 1 was marked totally incorrect in question 7.5. The remaining 16 learners were marked partially correct because they were able to identify the formula that was supposed to be used to solve the problem but could not proceed further.

These results suggests that the area formula [$A = \pi r^2$] and the induced emf formula [$\varepsilon = -N\Delta\Phi/\Delta t$] were the only formulae that learners could easily identify. These formulae accounted for the high number of learners who were marked partially correct in questions 7.3 and 7.5. The results also suggest that rate of change of flux formula [$\Delta\Phi/\Delta t$] and Ohm's law formula [$R = \varepsilon/I$] were the formulae which most learners struggled to identify. The high number of learners who were marked totally incorrect in questions 7.4 and 7.6 confirm that most learners could not identify these formulae.

The fact that a significant number of learners was marked partially correct but not totally correct in questions 7.3 and 7.5 suggests that these learners were able to connect knowledge of the concepts with the problems as they were in a position to identify the given variables and relevant formulae. Their inability to proceed beyond the identification of the formula suggests that most of them had mathematical rather than conceptual challenges. Figure 6.9 shows responses of two learners who had mathematical challenges:



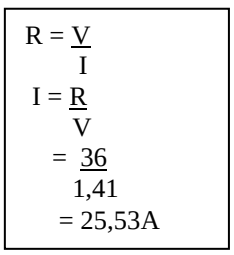


Figure 6.9: Responses of learners 1 and 2 respectively

Learner 1's answer was marked partially correct because she identified the correct area formula. However, her second step was incorrect since she did not convert 2,5cm to 0,025m before determining the product. Learner 2's answer was marked totally incorrect because instead of writing R = V/I as I = V/R she wrote it as I = R/V.

6.4.2 The Domains

Subject matter knowledge

Rollnick *et al.* (2008) refers to subject matter knowledge as 'raw untransformed' knowledge of the subject matter as viewed by its domain experts. Subject matter knowledge includes knowledge of concepts, laws, rules and principles governing a particular subject matter and how this subject matter is structured. In this aspect of teacher knowledge, I discuss how the transformation of this knowledge and its ultimate structuring into sequential lessons assisted me in presenting the topic to the learners. In the following paragraphs I discuss how I assisted my learners to conceptualise the definitions, laws, rules and the principles of EMI.

Perhaps the most important form of learning that I experienced while learning the topic was discovering that EMI is a process. While constructing concept maps, it became clear to me that EMI is a process consisting of a series of events which start with magnetic effects setting up an induced emf in the conductor and culminating in electric current produced. The complete process of EMI as I learned to understand it is depicted in Figure 6.4 above. Understanding the EMI process was instrumental in establishing the sequence which the lessons of the topic would follow. It was after I learned the process of EMI that I decided how I would follow the lessons as depicted by the overall instructional strategy discussed above.

The EMI process assisted me in defining the concept of EMI to my learners. Figure 6.10 shows the concept map of the EMI process that I constructed with the learners on the chalkboard to assist them in conceptualising the concept.

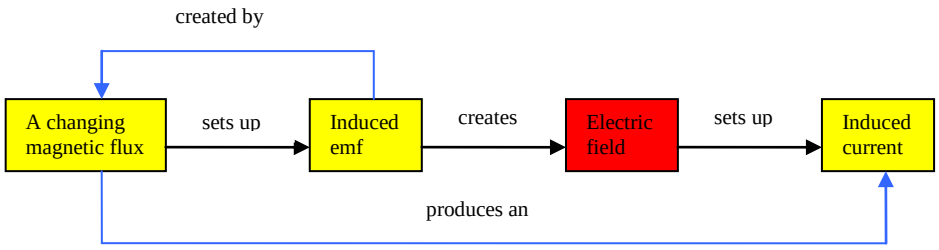


Figure 6.10: Process used to define EMI

The blue arrow lines moving in an anticlockwise direction from the 'induced emf' textbox to the 'changing magnetic flux' textbox and eventually to 'induced current' textbox show how I taught my learners to define EMI. The concept map shows how I constructed a proposition that led me to define EMI as follows to the learners:

> EMI is a process whereby an ***emf is induced*** by a ***changing magnetic field (flux)*** to produce an ***induced current***.

Teaching learners in this way was important since not only did this approach assist them to conceptualise EMI but also showed the importance of understanding the EMI process.

Very few grade 11 textbooks that I encountered when I was learning about the topic explicitly distinguish between the concepts used in electric circuits and EMI. When I was learning the topic, I realised that it was very important to make my learners aware of this discrepancy. Thus, when teaching concepts such as induced current and induced emf I made my learners aware that these concepts differed from those used in electric circuits. As already reported herein, learners were made aware that both the current used in electric circuits and the induced current they encounter in EMI entail the flow of electric charge and that the difference between these two currents were their sources. They were also made aware as reported earlier in the study that the source of current in electric circuits is the battery whereas the source of induced current was the changing magnetic flux. Thus, the induced current was defined as '*electric current produced by a changing magnetic field'*. Defining induced current in this way made learners aware that electric current can be produced by other means other than a circuit connected to the battery.

The grade 11 curriculum expects learners to define magnetic flux as the "*product of magnetic field strength and the area enclosed by the closed conductor"* (DoE, 2006,

p. 66). This definition is rather procedural than conceptual in that learners who know the formula $\Phi = BA$ can easily state it. Thus, to help my learners conceptualise this concept rather than memorise it, I used the diagrams represented in Figure 6.11 to explain the concept.

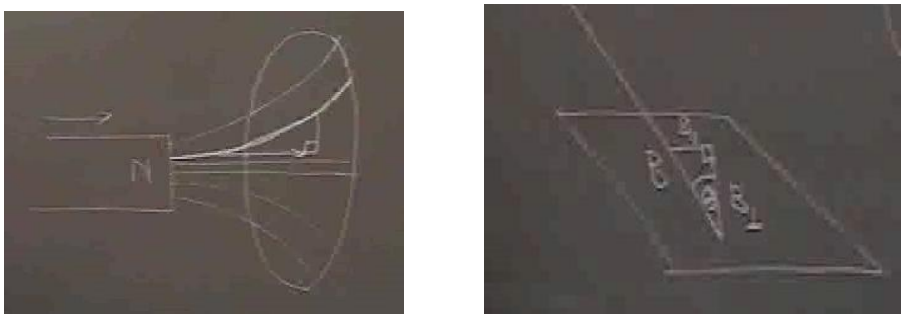


Figure 6.11: Diagrams used to conceptualise magnetic flux

The two diagrams were used to show the learners that it is the vector component of the magnetic field lines that runs perpendicularly through the area enclosed by the conductor that is considered as magnetic flux. Thus, magnetic flux was defined (as explained in Giancoli) to the learners as:

> Magnetic field that passes perpendicularly through the area enclosed by the conductor;
> Or
> The total number of field lines that passes perpendicularly through the area enclosed by the conductor.

The second definition also sounds mathematical just like the one they are expected to use in the grade. However, this one is helpful to the learners considering that magnetic fields are generally represented by field lines than the strength of the magnetic field which is difficult to conceptualise.

Certain aspects of my teaching revealed that my knowledge of the subject matter was not yet adequate. The word 'oppose' in Lenz's law proved to be a challenge when I explained the law to the learners. Initially, I thought the directions of the two magnetic fields were the ones that should oppose each other in order for the direction of the current to be determined. However, I realised during instruction that this notion is true for the increasing magnetic flux but not for a decreasing magnetic flux. Thus, it was after I had taught the lesson that I realised that the concept of 'oppose' was referring to motions of the conductor and the magnet and not the directions of the magnetic fields provided by the magnet and current in the conductor. Sears, Zemansky and Young (1980) argue that the concept of 'oppose' in Lenz's law may be

associated with "the motion of a conductor in a magnetic field or the change of flux through a stationary circuit" (p. 576).

The diagrams shown in Figure 6.12 illustrate how I later came to understand the concept of 'oppose' in Lenz's law:

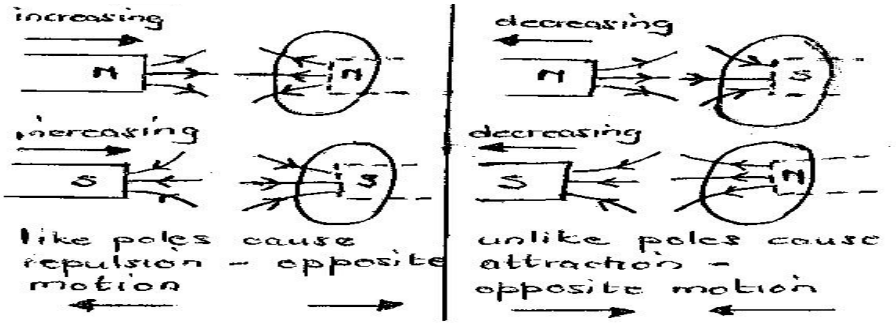


Figure 6.12: Diagrams showing the motion of conductor and magnet for increasing flux and decreasing flux.

According to these diagrams, an increasing flux results in two magnetic fields with the same poles facing each other, suggesting that the conductor and the magnet will repel each other. On the other hand, the decreasing flux results in the two magnetic fields with opposite poles facing each other, suggesting that the conductor and the magnet will attract each other. Thus, both the attractive and repulsive effects of the conductor and magnet always result in opposing motion (Broster *et al*., 2006).

Some of the questions that were posed by the learners during instruction suggested that I still needed to further develop my subject matter knowledge of the topic. Two such questions that perhaps exposed my lack of adequate knowledge on the topic are given below:

> Learner 1: Sir, how does a magnetic field pass through a solid?
>
> Learner 2: Can they [geologists] use it [seismograph] to determine whether a volcano is going to erupt or not? Because when the volcano is about to erupt there is some vibrations.

Learner 1's question arose after he observed that the solenoid they were using was made of a hollow plastic material from which a wire was rolled around. This led the learner to wonder how the magnetic field around the magnet that was inserted in the hollow area of the solenoid would pass through the plastic material to induce the current in the wire.

This question caught me by surprise as little did I anticipate that I would be asked such a question. I tried to answer the question using the domain theory but I could see that my learners were not satisfied with the answer. I ended up informing them that I would look for the answer elsewhere and provide it back to them as soon as I had found it. The only answer I could provide to the learners, after several days of searching, was that magnetic fields do pass straight through non-magnetic materials (such as paper, plastic and glass) depending on how thick the material is compared to the strength of the magnetic field as well as the degree of permeability (wiki.answers.com, 2009). According to my understanding, a strong magnetic field would pass straight through a thin non-magnetic material (high degree of permeability) but would not do so if the material was too thick (low degree of permeability).

Learner 2's question exposed my ignorance regarding knowledge of the topic which fell outside the Physical Sciences curriculum. Learner 2's question was based on his understanding that volcanic eruptions are preceded by seismic activities such as tremors and earthquakes. His knowledge of Geography and the new knowledge on EMI prompted him to think of alternative devices other than the ones that were specifically meant to monitor volcanic eruptions. When learning about how the seismograph uses the EMI process, never did I think of other situations where this device could be used other than in detecting earthquakes. This question highlighted the need for me to learn to link the topic not just with other topics in Physical Sciences but also with other subjects.

Knowledge of learners

The videotaped lessons revealed how the knowledge that I had about my learners assisted me in presenting the lessons on the topic. Such knowledge of learners assisted me in formulating ways of enhancing their learning by employing various teaching strategies and procedures. Knowledge of learners that I brought into the classroom enabled me to: (i) select learning and teaching styles which suited them, (ii) formulate ways of scaffolding their learning, (iii) identify their learning difficulties, (iv) use

their prior knowledge to introduce them to new knowledge, and (v) identify and use misconceptions which they held to redress their challenges.

The knowledge I had about my learners prompted me to approach the lessons differently from the approach followed by their curriculum. The curriculum proposed that I start with Faraday's law but this approach would not suit my learners as they did not have any knowledge of the EMI process yet. Thus, when introducing the topic I started by engaging my learners to a practical activity that required them to observe the EMI process before we discussed it. The decision to follow this approach was based on the fact that I knew that they learn better when working in groups and observing a scenario before learning more about it. As a result, the teaching procedures that I used in the lessons were chosen based on their preferred learning styles rather than the style suggested by the curriculum.

Knowing that my learners had problems understanding English (their medium of instruction) prompted me to formulate ways of addressing these challenges during instruction. During instruction learners were allowed to express their ideas in their mother language and whenever necessary I would also use their mother languages to explain what they found difficult to understand. Knowing that they had language difficulties prompted me to prepare tasks that scaffold their learning. The practical activity worksheets were designed in such a way that it required them to focus more on the task at hand than to worry much about the language. Thus, their practical activity worksheets, to a large extent, required them to complete statements by supplying one word or phrase and to choose the correct answer from those that were provided (Appendix I).

Scaffolding their learning was also done by asking leading questions which eventually took them to the expected answer. The following excerpt depicts how I assisted my learners to eventually answer the questions that I had initially asked:

> Teacher: Can a [changing] magnetic field produce electric current? (Silence).When we were doing these experiments did we produce any current? (Silence). When we moved the magnet into and out of the coil was there any current that was produced?
> Learners: Yes [chorus].
> Teacher: How do you know [that]?

Learner 1: The galvanometer needle deflected.

Teacher: Indicating that there is?

Learners: electric current [chorus].

The initial question wanted learners to confirm if a changing magnetic field can produce electric current. The silence that followed the question suggested that learners were unsure of the answer to the question. Hence, I decided to rephrase or break down the question into smaller leading questions that would assist them to eventually answer the main question that was posed initially.

Other problems associated with language difficulties included learners' inability to use correct words or phrases when explaining certain concepts. During instruction, some learners used words which did not fit in the explanation resulting in wrong meaning of the explanations. The following excerpts illustrate the point:

Learner 1: the induced emf is 'converted into' a changing magnetic field.

Learner 2: it [the needle] remains 'constant'.

Learner 1 used the phrase 'converted into' instead of 'created by' or 'set up by'. Such a phrase gives an impression that emf can be changed into a changing magnetic field when this is not the case. Learner 2's answer was in response to the question I had asked earlier on. The question wanted to find out what happens to the galvanometer needle when the magnet is held stationary inside the coil and the learner answered that it remains 'constant' instead of saying it remains 'stationary' 'still' or 'does not deflect'. Taber (2001) argues that such inappropriate use of words in explanations leads to incorrect meaning of statements and eventually misconceptions. These problems were addressed during instruction because these words are not just used in this topic only but are also used in other topics in the whole of science.

Some of the knowledge of learners that emerged during instruction concerned the knowledge which indicated that they were beginning to conceptualise the EMI topic. Some of the questions that they asked showed that they were beginning to link what was taught with what they experienced in their everyday life. The following question extracted from one of the lessons illustrates the point:

Learner 1: Will the bulb connected to the solenoid glow if a magnet is moved in and out [of the area enclosed by] the solenoid?

This question was asked by learner 1 after the class was introduced to the EMI process. Learner 1's question suggests that she has observed that the process of EMI is another way of generating electric current. The question suggests that the learner was beginning to associate what she had just learned with other situations with which she is familiar. The same statement could be said about the learner who asked whether a seismograph could be used to determine volcanic eruptions earlier on. His ability to link what he learned in Geography with the new knowledge he had just acquired suggested that he was beginning to conceptualise the topic.

Perhaps the most disturbing knowledge I learned about the learners was their inability to transfer what they had learned in the previous grade to the topic at hand. This misconception emerged when learners were supposed to determine the directions of the opposing magnetic fields during the process of EMI. Figure 6.13 illustrates how a learner answered the question I had asked them earlier on:

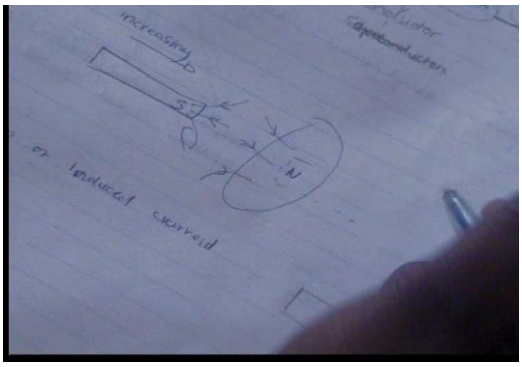


Figure 6.13: Learner's response to question requiring her to determine the direction of the induced magnetic field

The learner was able to follow the method of determining the directions of the two magnetic fields but was unable to determine the imaginary pole that would be created by the induced magnetic field. Had the learner known the directions of the magnetic fields near the magnet, she would have easily identified that the direction of the field induced by the current was the S-pole and not the N-pole as she answered.

6.5 Integrating my teacher knowledge

The results of curricular saliency reveal how I interacted with the curriculum and transformed it into knowledge that would be comprehensible to my learners. The development of my curricular saliency was revealed by the decisions I made with regards to deciding what to teach and not teach as well as how to teach the topic. Knowledge of the subject matter, learners and context played a prominent role in transforming the curriculum. Sound knowledge of my subject matter was required in deciding what to include and exclude in my instruction. The decision to opt for practical activity rather than use illustrations to explain the EMI process confirmed that I had sound knowledge of how my learners learn. Interacting with the curriculum to determine what was included and omitted confirmed that my knowledge of context also played a role towards the development of my curricular saliency.

The results reveal that the overall instructional strategy was informed by knowledge of subject matter, knowledge of learners and general pedagogical knowledge that I had developed. The overall instructional strategy reveals the amount of subject matter knowledge that I had acquired and how this content was structured to explore the big ideas of the topic. Knowledge of learners regarding how they prefer to learn and their learning difficulties informed the teaching strategies that I employed during lesson presentations. The sequencing of lessons followed was influenced by learners' preferred style of learning as well as the lesson objectives of the topic. These teaching strategies and the way the lessons were sequenced were in turn informed by the general pedagogical knowledge that I had developed.

The results also reveal several ways that were used to transform subject matter into knowledge that can be accessible to the learners. Subject matter representations were used to link learners' prior knowledge with new knowledge, develop learners' conceptual understanding and stimulate interest in the topic. Knowledge of selecting relevant representations and the awareness of the dangers associated with using representations confirmed the general pedagogical knowledge that I brought in the teaching of the topic. The extensive use of concept maps in the lessons reflected how my SMK had developed as well as how it was connected. However, the inability to provide sufficient analogies when presenting the topic suggests that my SMK had not

yet fully developed. These results confirm that SMK, knowledge of learners and general pedagogical knowledge played an important role in deciding the representations that were used in the topic.

Knowledge of context played a role in preparing the test as the curriculum had to be used to set the test. My knowledge of the subject matter was also required to set the test as well as to provide the memorandum for the test. The results of assessment focused largely on knowledge of the learners regarding their responses on the test. Their inability to respond totally correct on the questions confirmed that most of them still lacked adequate knowledge of the topic or that their knowledge was still in the early developmental stages. Their learning challenges revealed that some learners had not fully conceptualised the topic, some were unable to connect concepts learned to their practical application and some still carried misconceptions. Some of the learners' misconceptions may have been as a result of my teaching because my SMK had not fully developed either.

6.6 Conclusion

The results of the analysis reveal that all four domains played a role in informing the manifestations. Subject matter knowledge and knowledge of learners featured in all manifestations with knowledge of context and general pedagogical knowledge featuring interchangeably amongst the manifestations. The emergence of the domains in the manifestations revealed how the domains integrated to produce PCK. The featuring of the domains in the manifestations confirmed the importance of PCK in developing ways of transforming subject matter into knowledge that is accessible to the learners.

The emergence of the categories of subject matter knowledge and knowledge of learners in the analysis was not surprising considering that the study focuses on learning the topic and then teaching it. The two domains highlight the importance of sound knowledge of subject matter as well as the understanding of the learners and their behaviour in ensuring effective teaching practice. The featuring of SMK in all manifestations confirmed the role played by SMK in the development of my PCK. To

be able to teach effectively, I had to develop sound knowledge of the topic and then transform it into knowledge comprehensible to the learners.

The featuring of knowledge of learners in the manifestations revealed how important it was for me to tailor the instruction according to my learners' needs based on knowledge I had about them before teaching the EMI topic. In transforming the subject matter, I had to ensure that I had adequate understanding of learners' prior knowledge, possible misconceptions, preferred learning styles and any other learning challenges that they were likely to encounter during the presentation of the topic. The knowledge that I learned from the learners during instruction also contributed towards the development of my PCK. Their learning challenges which I observed during instruction were remediated and also recorded in the reflection sections of the lesson plans for future references.

The results suggest that in as much as there was progress with regards to the development of my PCK, certain aspects of my teacher knowledge still required some further development. Although I had acquired a substantial amount of subject matter knowledge of the topic, it seems that this knowledge was not yet fully entrenched in me as my teaching was not as flexible as I would have liked. This 'not so well-established' knowledge made it difficult for me to realise and utilise all the available means that would have otherwise enhanced my PCK. However, Rollnick *et al.* confirm that the development of PCK is a slow process requiring both time and opportunity to experiment.

Chapter 7 is a concluding chapter focusing on whether or not the study succeeded in achieving what it set out to do. The chapter starts by discussing the findings of the study and the two research questions set forth in the study. It continues to look at the limitations of the study and how these can be addressed. The chapter also looks at the recommendations that the study proposes and concludes by focusing at the implications that the study suggests for future research.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Introduction

This chapter discusses the concluding remarks regarding the research study. The chapter begins with a brief overview of the whole study which is followed by a discussion of the findings. The chapter then proceeds to discuss the research questions before commenting on the reflections of the study wherein the strengths and limitations of the study are discussed. The chapter culminates by looking at the recommendations which derive from the study and the directions for future research.

7.2 Overview of the study

This study set out to monitor how my knowledge of the subject matter and teaching practice develop as I learn and teach the topic on *electromagnetism* to grade 11 learners. The study focused on the EMI part of *electromagnetism* as this was the section which I found to be most challenging in the topic. The study mainly used concept maps to monitor the development of my subject matter. CoRe and PaP-eR were used to capture and document how I transformed the subject matter into knowledge accessible for teaching. The video-recordings of the lessons that were presented were used to capture aspects of teacher knowledge that contributed towards the development of my PCK and that which still needed development.

The study used two analytical methods of analysing concept maps identified by Hough *et al.* (2007). Structural analysis was used to analyse conceptual acquisition, connectedness and complexity of the three concept maps. The Rollnick *et al.*'s model of PCK was used to analyse the content of the three concept maps. The CoRe and PaP-eR were analysed using elements of teacher knowledge identified in the Rollnick *et al.*'s model as domains and manifestations. The CoRe captured knowledge of subject matter that I had developed during the learning of the topic whereas the PaP-eR articulated those aspects of teacher knowledge that informed my teaching of the topic. Video-recorded lessons were also analysed using the Rollnick *et al.'s* model to

establish the domains and manifestations of teacher knowledge that informed the development of my PCK during teaching practice.

The study concludes by discussing the salient features of the findings. Aspects of teacher knowledge which contributed to the development of my subject matter knowledge and those which contributed in transforming this knowledge into teachable form are highlighted with a view to addressing the research questions set forth in the study. To reiterate, the limitations of the study are discussed under reflections of the study after the research questions have been addressed. Recommendations for the learning and teaching of the topic as well as the directions for future research are discussed towards the end of this chapter as already mentioned in section 7.1.

7.3 **Discussion of the findings**

The findings portrayed and documented herein are the summary of the results captured in the analyses of the concept maps, CoRe and PaP-eR, and video-recordings of the lessons discussed in the preceding chapters. These findings describe how my PCK of the topic on EMI developed as I constructed the concept maps, CoRe and PaP-eR, and presented the lessons to my learners during the research project. The discussion focuses first on how each instrument contributed towards the development of each aspect of my teacher knowledge. Finally, the findings of the three instruments are integrated to articulate how these instruments assisted in developing my PCK.

Concept Maps

The results of the structural analysis of the concept maps revealed that the concept maps grew in size, complexity and connectedness each time they were drawn at a particular stage of learning and teaching. The results show that the first concept map contributed 28,3%, the second map 30,2% and the third map 41,5% of the total number of concepts that I acquired during the entire period of study. Firstly, these results suggest that conceptual learning did occur in-between the constructions of these concept maps. Secondly, they also suggest that more meaningful learning took place in the final stages than in the early stages of learning. This is understandable

considering that the third concept map was drawn towards the end of the study after I had developed well-coherent knowledge structures of the topic.

The increase in the complexity scores each time the concept maps were drawn suggests that my knowledge structures were becoming more complex and detailed as learning progressed. The fact that all the highest width numbers came from the second level of each map structure and that these numbers contributed more than the depth numbers, suggests that conceptual acquisition was directed more towards the development of the main concepts of the topic than the other concepts which were lower down the levels. The increase in the levels of connectedness revealed that my ability to group and order concepts into meaningful ideas and to relate the concepts to each other were also growing. However, this growth was more as a result of connecting ideas than grouping them.

The results of content analysis of the concept maps revealed that the EMI topic consisted of concepts, rules, laws and principles just like any other topic in the discipline. The results further revealed that each main concept of the topic was structured in such a way that it consisted of the definitions, formulae, units of measurement, factors influencing their magnitude and directions, and how each concept is applied in everyday situations. These findings are consistent with Shulman's views of subject matter. Shulman (1986) refers to subject matter knowledge as the amount and organisation of knowledge as viewed by its domain experts and that this knowledge includes concepts, laws and theories that govern the discipline.

The results of content analysis of the concept maps also revealed other aspects of teacher knowledge which concerned the transformation of subject matter knowledge into teachable knowledge. These aspects of teacher knowledge included all the domains and manifestations that are portrayed in Rollnick *et al.'*s model of PCK. These results were not surprising because when I was constructing these concept maps I was also concerned about how I was going to teach the content related to them. Rollnick, Mundalamo and Booth (2008) maintain that teachers' concept maps are likely to reveal both aspects of content knowledge and pedagogical knowledge since

when they construct concept maps their knowledge of subject matter is intimately linked to how they are going to teach it.

CoRe and PaP-eR

The results of the analysis revealed how the CoRe assisted me in transforming the subject matter knowledge that I had acquired after constructing the concept maps. The results revealed that the big ideas that I formulated during the construction of the CoRe were the amalgamation of the content chunks which had developed into simple propositions in the concept maps. These propositions were probed and refined before they could be combined to form big ideas. This exercise suggests that when I was constructing the big ideas my knowledge structures were continuing to group, organise and connect ideas into meaningful thoughts. This means therefore, that the conceptualisations of the big ideas were the results of the transformation of content knowledge using my pedagogical reasoning.

A closer inspection of the big ideas that were constructed during this study revealed another dimension of knowledge that I had not anticipated. These big ideas turned out to be four crucial pieces of information that helped me summarise the whole topic on EMI. Understanding each of these big ideas and knowing how they connect meant that I could easily summarise the whole topic or teach it without referring to any curriculum document or textbook. However, as suggested by Loughran *et al.* (2006), big ideas are not just summaries of the content but the transformation of content into knowledge accessible for teaching. They do not represent sections of content to be covered per se but ways that help shape the conceptualisation of that content (Loughran *et al.*, 2006).

The results also showed how the prompts compelled me to articulate aspects of learning and teaching that assisted me in transforming the big ideas in ways that enhanced conceptual learning. By interacting with the prompts, I was able to make informed decisions about what to teach and not to teach, how the lessons would be sequenced, which teaching strategies and ways of representations I would employ as well as ways of ascertaining learners' understanding or confusion. Through interacting with the prompts, I was able to pre-empt from the big ideas learners'

potential challenges and contextual factors that might hinder their understanding of the topic and ways that these challenges could be remediated.

These results are in line with the Loughran *et al.*'s (2006) findings which maintain that the prompts are helpful in unpacking the big ideas "so that specific information about the big ideas that impact on the manner in which the content is taught can be made explicit" (p. 21). In this study, the CoRe assisted me in articulating the pedagogical decisions that I would take when teaching the topic to the learners. These decisions were informed by my knowledge of the subject matter, learners, context and the general pedagogical knowledge which according to the Rollnick *et al.*'s model constitute the domains of my PCK.

The PaP-eR that I developed presented an account of how I intended to transform the subject matter knowledge that I had learned in ways that could be understood by the learners. The results revealed aspects of teacher knowledge that I employed which informed the way I presented these sections of the topic. These aspects of teacher knowledge covered the elements of the Rollnick *et al.'*s model that represented the manifestations. These results were not surprising as Loughran *et al.* regard PaP-eRs as windows into a teaching situation which illustrate aspects of teacher knowledge in action. Through the PaP-eR, I was able to provide insight into how I combined my elements of PCK to transform my knowledge of the topic into knowledge that enhanced conceptual learning.

Video-recorded lessons

The results of the video-recorded lessons revealed several categories of transforming subject matter as suggested by the Rollnick *et al.'*s model of PCK. These categories of teacher knowledge include all four manifestations chosen for the study as well as the two domains, namely subject matter knowledge and knowledge of learners. The results revealed examples or instances showing how I used aspects of my curricular saliency to carefully choose the material that I presented to my learners. The overall instructional strategy revealed the amount of subject matter that I presented during the lessons and how this was sequenced to unpack the big ideas of the topic.

The results also revealed the subject matter representations that I used during instruction delivery and the criteria I used to select them. These representations were used to link learners' prior knowledge with new knowledge, develop their conceptual understanding and stimulate their interest in the topic. The results of assessment category revealed how I integrated my knowledge of the domains of PCK to prepare the test. The results of the test confirmed that although there was some form of conceptual development that took place, some learners still lacked the necessary basic knowledge of the topic whereas others were still in the early conceptual development stages of learning the topic.

Although all the four domains of PCK played a role in informing the manifestations, subject matter knowledge and knowledge of learners stood out to be the dominant domains that assisted me in transforming the subject matter. Their emergence throughout the manifestations confirmed the role played by subject matter knowledge and knowledge of learners in transforming the curriculum into teachable knowledge. Instances where my teaching practices were found to be lacking were as a result of one or both of these domains not having had notable positive influence on the transformation of the curriculum. Instances where these domains had positive influence were marked by lesson presentations where I had full control of the learning and teaching environment.

The above discussions revealed how interacting with various curriculum documents assisted me in constructing the concept maps which represented my knowledge structures of the topic on EMI. The findings revealed how the concept maps which were initially meant to monitor the development of my subject matter knowledge turned out to contribute towards the development of other domains of my PCK. The results also showed how the development of the CoRe and PaP-eR contributed in transforming the subject matter knowledge I had acquired into knowledge accessible for teaching. The video-recorded lessons portrayed how my teaching practice had developed by the time I presented the topic to the learners.

Thus, all three instruments that were used in the analysis of data contributed one way or the other in the development of my PCK. Their results revealed how each of these instruments informed both the domains and manifestations of my PCK. The findings

also show how these aspects of teacher knowledge were intertwined to produce my PCK. Although much of the learning did take place during the study, other elements of my PCK revealed that they still required some development. As already mentioned herein, Rollnick *et al.* argue that the development of PCK is a slow process requiring both time and opportunity to grow.

7.4 Answers to research questions

The aim of this study was to monitor the development of my PCK regarding the learning and teaching of the topic on *electromagnetism* to grade 11 learners. This section attempts to address the research questions set forth in the study.

7.4.1 Research question 1:

How does my CK develop as I learn the topic on electromagnetism?

The development of my content knowledge can be traced back from the moment I consulted the curriculum documents, literature and textbooks regarding the topic on *electromagnetism*. These source documents became helpful in constructing the concept maps which primarily portrayed evidence of my conceptual development. The first concept map was drawn after I had read the curriculum documents on the topic whereas the second map was constructed after I had read various textbooks and literature on the topic. The third concept map was constructed after I had completed teaching the topic suggesting that this map involved all the source documents that I had consulted from the beginning of the study.

The structural analysis of the concept maps revealed how my knowledge structures of the topic developed as learning progressed. The results show that the number of concepts, their complexity and connectedness grew during the study. The increase in the number of concepts acquired meant that my knowledge structures were growing in size whereas the increase in the complexity of the concept maps meant that my knowledge structures were developing from simple ideas into complex thoughts about the topic. The levels of connectedness meant that my knowledge structures were becoming organised and inter-related suggesting that I was developing a deep

understanding of the topic. These revelations are in line with Hough *et al.* who maintain that the structural analyses of the concept maps reveal how the knowledge structures of the mapper develop as learning progresses.

The extent at which my knowledge of the content developed could also be explained by the way I came to understand how the structure of the topic on EMI was organised. Through interacting with the various source documents I came to learn that EMI consists of fundamental concepts, mathematical formulations and observed phenomena just like Anderson and Mina (2003) discovered about the structure of *electromagnetism*. These mathematical formulations could be used to manipulate the fundamental concepts governing EMI in order to explain the observed EMI phenomena. The study also helped me to learn that the structure of EMI consisted of the concepts, rules, laws and principles that govern the topic just like Shulman observed.

The study has instances revealing how my content knowledge developed throughout the study. These instances were revealed as the salient features of the topic in the PaP-eR. Learning about the existence of the EMI process proved to be the most piece of knowledge I acquired because this process was not explicitly revealed in the textbooks and curriculum documents. It was through trying to piece together what exactly governed this topic that I became aware of the existence of this process. Discovering the process of EMI opened ways for me in that I was able to discover the two principles of generating induced current, to conceptualise the main concepts of EMI as free-standing knowledge structures as well as establish how they are inter-related.

Learning both methods of determining the direction of the induced current suggested by the school textbooks and Giancoli (2005) contributed towards the development of my content knowledge as the confusion that I initially had about the directions of induced current and the two magnetic fields involved in the EMI process was eradicated. Learning to apply the process of EMI in different situations where it is applicable proved to be the ultimate test of the extent of my conceptual development about the topic. Understanding the process of EMI enabled me to explain how instruments such as the microphones, seismographs, electronic card swiping machines

and induction stoves operate. It is when one has learned how the principles governing that particular discipline works that one can claim to have mastered the discipline (Shulman, 1986).

7.4.2 Research question 2:

How does my PCK develop as I teach the topic on electromagnetism?

The development of my PCK is also traced back as early as when I constructed the concept maps. During concept map constructions certain aspects of teaching the topic began to surface. Phrases such as 'solve problems', 'words and pictures', 'artefacts' and others which are classified as non-scientific concepts in Appendix B revealed that my knowledge structures were beginning to transform the content knowledge I was acquiring into knowledge for teaching. The emergence of these non-scientific concepts meant that the other domains of my PCK, namely knowledge of the learners, general pedagogical knowledge and knowledge of the context, were transforming the content knowledge I was learning.

The formulation of the big ideas of the CoRe also showed how the domains of my PCK played a crucial role in transforming the content knowledge I had acquired. All the four big ideas were derived from content-specific science ideas that I felt formed the core of the topic. These science ideas were manipulated and amalgamated using my knowledge of the learners, curriculum, context and educational aims of the topic to transform them into big ideas. Further probing of the big ideas using prompts demanded that I used all four domains of my PCK to explicitly articulate how I intended to present the topic to the learners. The salient features of the topic discussed in the PaP-eR gave account of how I intended to unpack the transformed content knowledge using pedagogical reasoning in the classroom.

The development of my PCK during instruction delivery was also confirmed by the actions that I undertook during the presentations of the lessons. The findings of the study revealed how I used my curricular saliency to carefully decide what I would teach my learners about the topic. The findings also revealed how I chose the topic-specific instructional strategies and subject matter representations to ensure that

effective learning and teaching took place. The findings went further to reveal how I set out to prepare all the assessment tasks that I would use to ascertain learner understanding or confusion about the topic. All these actions demanded that I integrated the domains of my PCK to transform what I learned into knowledge for teaching.

Teaching the topic to the learners made me aware of certain aspects of learning and teaching that I did not anticipate when preparing to teach. During instruction I was able to test the depth of my understanding regarding the content knowledge and knowledge of pedagogy that I had developed about the topic. Teaching the topic afforded me the opportunity to establish things that needed to be rectified in my practice. For instance, it was through instruction that I realised that I had to review my understanding of Lenz's law after I had misinterpreted it during the lesson. It was also through teaching that my knowledge of the topic further developed as some of the contributions made by the learners during discussions and questioning provided me with invaluable knowledge of how to teach the topic in future.

The findings regarding instruction delivery also revealed certain concerns about the state of my teaching practice. Although I made immense progress about the development of my teaching practice, certain aspects of my teacher knowledge still needed development as some of my lessons did not go as smoothly as I would have liked. Constant referring to the lesson plans during instruction suggested that I was still uncertain about my knowledge of the topic or other pedagogical aspects of my teaching practice. Such elements of uncertainty may be as a result that I was teaching this topic for the first time. However, if this is not the case then this means that I have to identify the cause for these concerns and address them before I teach this topic again.

The answers to these research questions point out how the four domains of teacher knowledge integrated to produce my topic-specific PCK. Each domain of my teacher knowledge played a role one way or the other in the development of my PCK. However, the role played by my content knowledge seemed to dominate other domains of my PCK. My teaching practice thrived in lessons where I had sound knowledge of the content and became rigid and restrained in lessons where my

content knowledge was limited. These revelations suggest that content knowledge must have played a central role over the other domains in the development of my PCK. Other researchers such as van Driel *et al.* (1998) and Rollnick *et al.* (2008) also maintain that content knowledge is crucial towards the development of one's PCK.

7.5 Critical reflections on the study

7.5.1 *The methodology*

This research chose autobiographical self-study as an approach to conducting a research on how I learn to teach a topic on EMI to grade 11 learners for the first time. Embarking on a self-study proved to be a challenging and yet rewarding endeavour. Self-study proved to be a lonely journey where I had to work alone most of the time in trying to resolve the dilemmas and frustrations I experienced about learning to teach this topic. The only human-sources of information I had to rely on were my supervisor, the learners I taught and only one physical sciences teacher in my school who did not have knowledge of the topic either but was always willing to discuss and assist wherever he could.

The methodology's ability to blend methods succeeded in ensuring that I addressed the research questions set forth in the study. Concept maps captured most of the content knowledge I learned and also revealed other aspects of teacher knowledge that were crucial in the development of my PCK. The CoRe and PaP-eR assisted me in transforming the content knowledge I had acquired into knowledge for teaching. The prompts of the CoRe also revealed the domains that informed my PCK as well as the manifestations that reflected the extent to which my PCK had developed. Teaching the topic to the learners assisted me in portraying aspects of my teacher knowledge that have developed and those that still needed further development.

The methodology used the Rollnick *et al.'*s model of PCK as the theoretical framework for the study. The model assisted me in the analysis of the concept maps, CoRe and PaP-eR, and classroom observations. The framework assisted in capturing and documenting the domains as well as manifestations of my teacher knowledge that emerged from these instruments. Although Rollnick *et al.* used this model in the

analysis of the CoRe and PaP-eR and in classroom observations, this model also proved to work well in the qualitative analysis of the concept maps where the typologies that were established were analysed using the domains and manifestations elements of the model.

7.5.2 *Limitations of the study*

Samaras and Freese (2006) maintain that in as much as self-study is an approach that focuses on the self and one's teaching practice, it is somehow a collaborative effort as it requires all the voices of the participants to be heard. While I worked collaboratively and amicably with my supervisor and my learners during the study, I feel the unavailability of more experienced science teacher in the school at which I work somehow hampered the development of my learning. There were times during the study when I needed immediate expert advice and/or emotional support as some of my dilemmas and frustrations that required immediate attention could not be resolved.

Opie (2004) warns that audio and video recordings can bring with them troubles associated with sound quality and participant behaviour. The use of audio and video recorders affected both the behaviour of my learners and mine during the lesson presentations. Although these recorders were used in a few lessons before the research lessons commenced (so that learners and I could get used to them), they turned out to be more of a deterrent than assistance. Some learners tried to act for the camera whilst others just froze in the presence of these instruments. These behaviours resulted in me discarding some of the audio data as some learners were too loud and some were too shy to speak in their presence. I also found myself intimidated by their presence especially in areas of teaching where my content knowledge was inadequate.

Loughran *et al.* (2004) worked with small groups of experienced teachers to develop a CoRe of a particular topic. Based on the exercise they undertook, it means that the construction of the CoRe should be a collective effort of teachers who are experienced in the topic rather than an individual exercise. In this study, I developed a CoRe individually and I was inexperienced in this topic because I had not taught this topic before. However, the construction of the CoRe in this study was paramount in that the CoRe assisted me in transforming content knowledge into knowledge for teaching.

The CoRe also assisted in helping me identify aspects of teaching which needed to be attended to before instruction delivery could take place.

Most topic-specific diagnostic tests tend to measure the conceptual development of learners rather than procedural learning. These tests are usually given before and after instruction to measure the progress that took place during the period of learning. A pre-test was not given to the learners as they did not have any prior knowledge of the topic on EMI. The post-test that I gave to the learners was set according to the criteria stipulated by the National Department of Education rather than in the way diagnostic tests are set. The test included questions requiring both conceptual and procedural learning. Since the analysis of the test results focused on both these aspects of learning, the measurement of conceptual development of learners may have been somehow compromised.

7.6 Recommendations

This study focused on how I went about learning to teach the topic on EMI. The study showed how knowledge of the content was crucial in ensuring that there was progress in the development of my PCK as I learned to teach the topic. Hence, the study recommends that science teachers should strive to acquire sound knowledge of the content in order to develop effective ways of teaching topics with which they may be unfamiliar. Rollnick *et al.* (2008) argue that sound knowledge of subject matter allow teachers the flexibility to produce innovative approaches to teaching and to teach with confidence.

Concept maps proved to be invaluable tools in assisting me to construct the knowledge structure of the topic. Through concept maps I came to understand the principles and laws that govern the topic of EMI as well as effective approaches and strategies of teaching the topic. The construction of concept maps at various stages of learning assisted me not only in tracking down the development of my content knowledge but also in how to teach the topic. Thus, the study supports the idea that concept maps can be used as valuable tools for monitoring and validating the progress of one's learning and teaching (Hough *et al.*, 2007).

The construction of the CoRe assisted me in the preparation of teaching the topic. Going through the prompts of each big idea gave me the opportunity to transform subject matter knowledge into knowledge for teaching. Through the CoRe I was able to focus on aspects of teaching such as content representations and teaching strategies that could assist learners to develop a better understanding of the topic. Thus, the introduction of the CoRe in schools and the training of science teachers in how to use the tool could assist teachers in exploring various aspects of teaching which they need to acquire before teaching the topic.

As already reported herein, various researchers such as Anderson and Mina (2003) and Sağlam and Millar (2006) acknowledge that EMI is an abstract concept that both teachers and learners find it difficult to understand. They also suggest various teaching approaches that could be employed to assist learners in developing a deep understanding of the topic. This study believes that the abstract nature of the concept could be better resolved by engaging learners in practical activities that demonstrate the existence of the EMI phenomenon before the actual conceptualisation of the topic could be introduced.

7.7 Directions for future research

Researches that have been conducted in *electromagnetism* have tended to focus more on learner misconceptions than on difficulties experienced by the teachers when learning and teaching this topic. Very few studies have focused on teachers' learning and teaching EMI especially at school level. This study only focused on the teacher's learning and teaching of the first principle of EMI where the induced electric current is generated by moving a magnet relative to a closed conductor. Future studies in EMI could be expanded to include the second principle of EMI where the induced current is generated by placing a conductor with alternating current next to the conductor that will induce the current.

Science teachers, irrespective of their academic qualifications and teaching experience, should look at the possibilities of engaging themselves in self-study research. Self-study research helps teachers to critically examine their practice, to discover ways of improving their practices, and to gain insights into their beliefs and

practices. My involvement in self-study research has encouraged me to become a life-long learner. It is through self-study research that my challenges, frustrations and dilemmas can be heard by other teachers and be addressed. Discovering ways of solving my problems on my own gives me a sense of ownership and empowerment.

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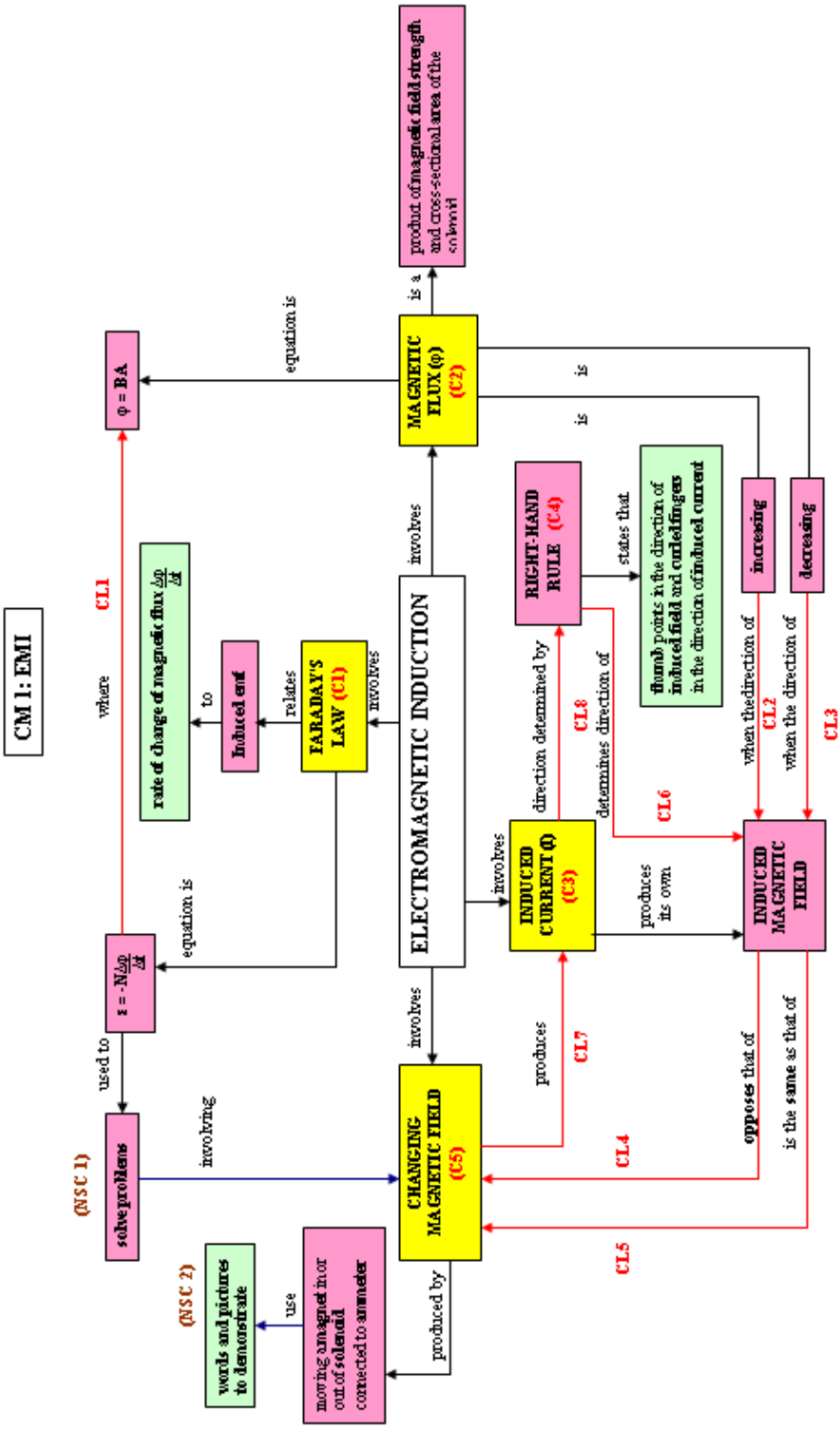
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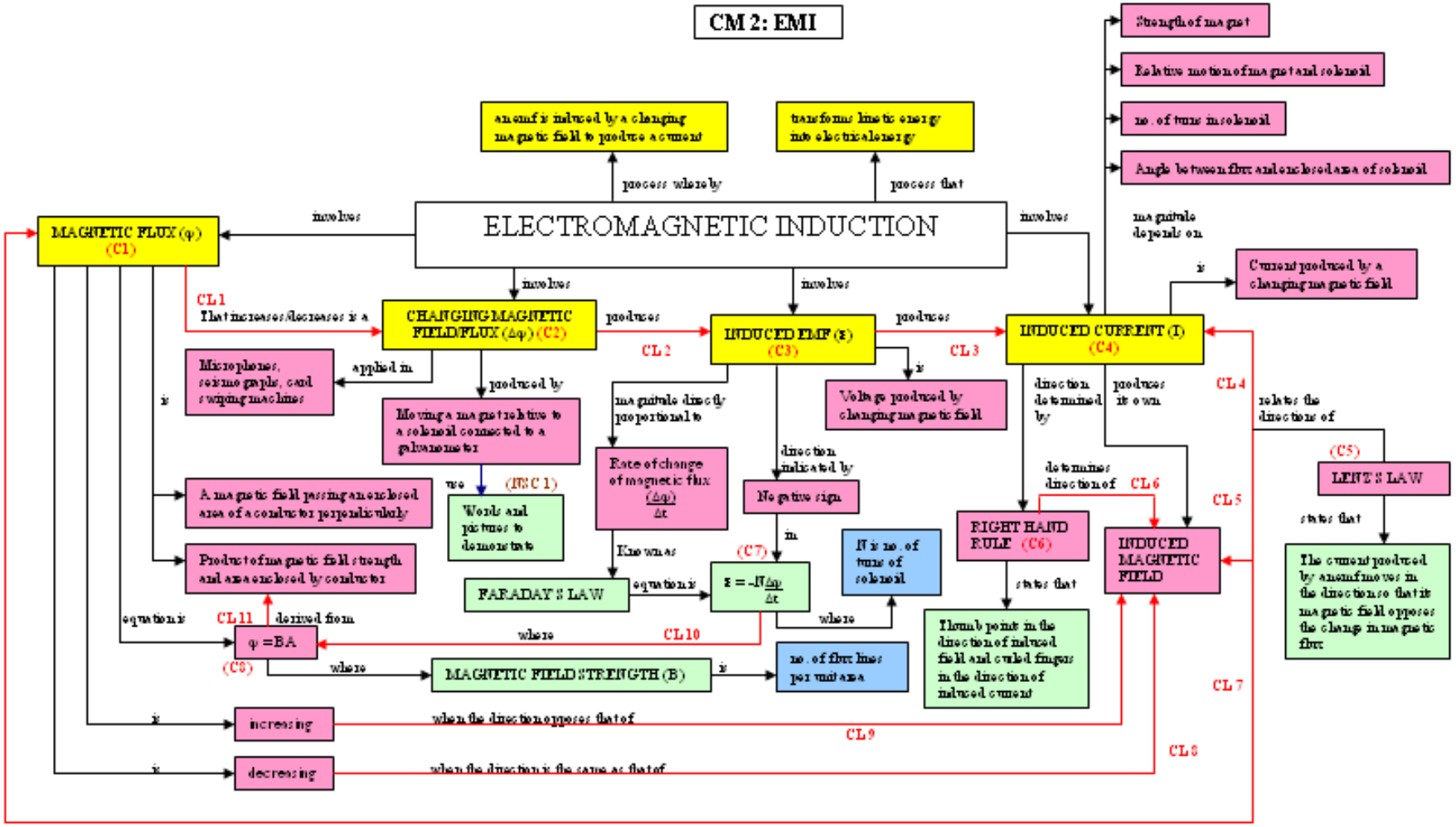
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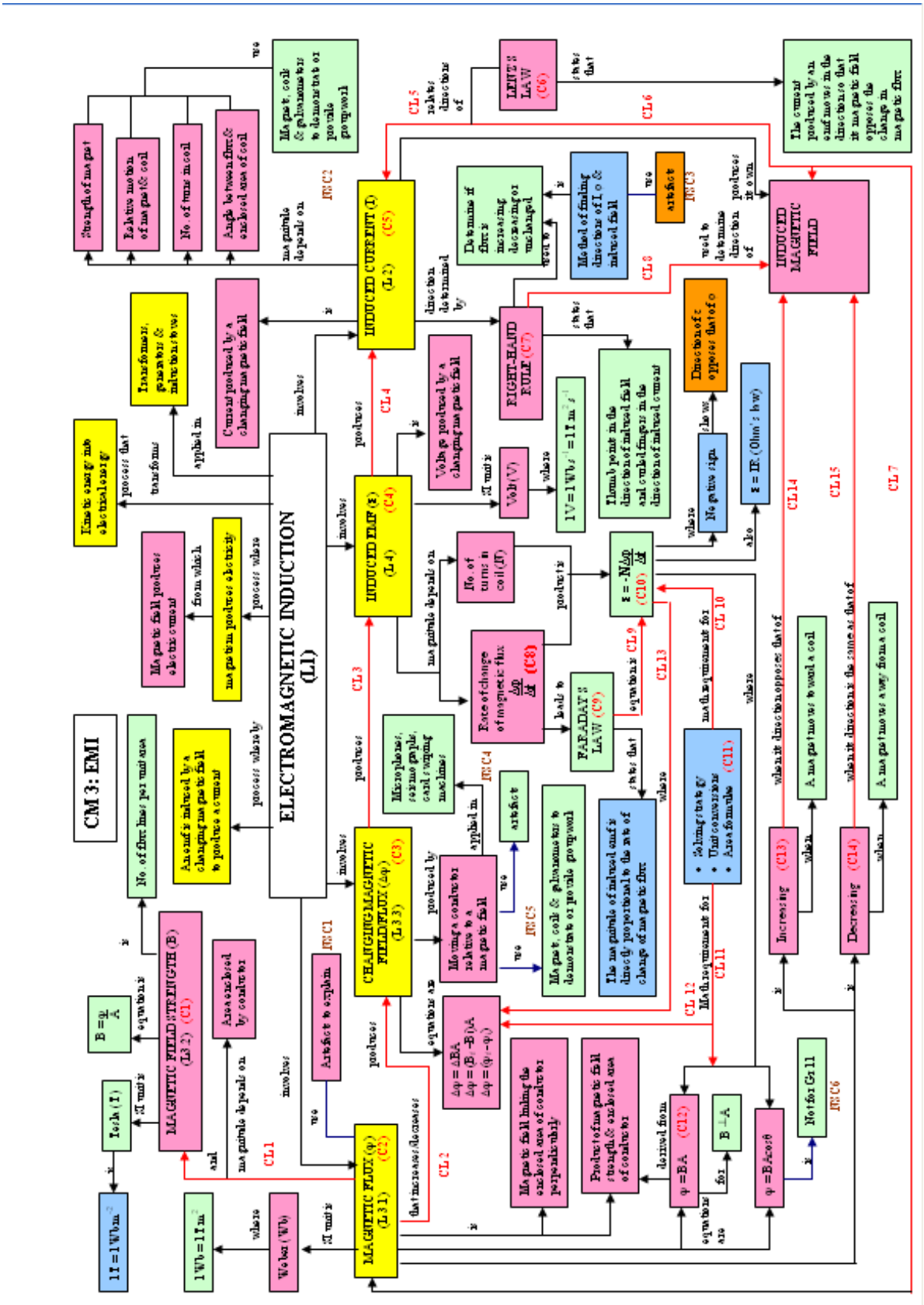
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APPENDIX A

The Three Concept Maps of EMI


CM 1: EMI
ELECTROMAGNETIC INDUCTION
FARADAY'S LAW (C1)
Induced emf
rate of change of magnetic flux $\frac{\Delta\phi}{\Delta t}$
$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$
$\phi = BA$
MAGNETIC FLUX (φ) (C2)
product of magnetic field strength and cross-sectional area of the coil
RIGHT-HAND RULE (C4)
thumb points in the direction of induced field and curled fingers in the direction of induced current
increasing
decreasing
INDUCED CURRENT (I) (C3)
INDUCED MAGNETIC FIELD
CHANGING MAGNETIC FIELD (C5)
solve problems
(NSC 1)
words and pictures to demonstrate
(NSC 2)
moving a magnet in or out of solenoid connected to ammeter
involves
relates
to
where
CL1
equation is
used to
involving
produced by
use
produces
CL7
direction determined by
CL8
determines direction of
CL6
produces its own
when the direction of
CL2
when the direction of
CL3
opposes that of
is the same as that of
CL4
CL5
states that
is
is
is a


CM 2: EMI
ELECTROMAGNETIC INDUCTION
process whereby
an emf is induced by a changing magnetic field to produce a current
process that
transforms kinetic energy into electrical energy
involves
MAGNETIC FLUX (φ) (C1)
involves
involves
CHANGING MAGNETIC FIELD/FLUX (Δφ) (C2)
produces
INDUCED EMF (ε) (C3)
produces
INDUCED CURRENT (I) (C4)
CL1
That increases/decreases is a
CL 2
CL 3
CL 4
is
Microphones, seismographs, card swiping machines
applied in
produced by
Moving a magnet relative to a solenoid connected to a galvanometer
Voltage produced by changing magnetic field
is
magnitude directly proportional to
Rate of change of magnetic flux (Δφ)/Δt
Known as
FARADAY'S LAW
equation is
ε = -NΔφ/Δt
where
N is no. of turns of solenoid
direction indicated by
Negative sign
in
(C7)
direction determined by
produces its own
relates the directions of
(C5)
LENZ'S LAW
states that
The current produced by an emf moves in the direction so that its magnetic field opposes the change in magnetic flux
CL 5
CL 6
determines direction of
RIGHT HAND RULE (C6)
states that
Thumb points in the direction of induced field and curled fingers in the direction of induced current
INDUCED MAGNETIC FIELD
CL 7
CL 8
CL 9
CL10
CL11
derived from
equation is
φ = BA
(C8)
where
MAGNETIC FIELD STRENGTH (B)
is
no. of flux lines per unit area
A magnetic field passing an enclosed area of a conductor perpendicularly
Product of magnetic field strength and area enclosed by conductor
(INSC 1)
use
Words and gestures to demonstrate
Strength of magnet
Relative motion of magnet and solenoid
no. of turns in solenoid
Angle between flux and enclosed area of solenoid
magnitude depends on
is
Current produced by a changing magnetic field
is
increasing
when the direction opposes that of
is
decreasing
when the direction is the same as that of


CM 3: EMI
ELECTROMAGNETIC INDUCTION (L1)
MAGNETIC FIELD STRENGTH (B) (L32) (C1)
MAGNETIC FLUX (φ) (L31) (C2)
CHANGING MAGNETIC FIELD/FLUX (Δφ) (L33) (C3)
INDUCED EMF (E) (L4) (C4)
INDUCED CURRENT (I) (L2) (C5)
LENTZ'S LAW (C6)
RIGHT-HAND RULE (C7)
FARADAY'S LAW (C9)
Rate of change of magnetic flux (C8)
Induced current produces its own magnetic field
Induced magnetic field
Tesla (T)
Weber (Wb)
Artefact to explain
Moving conductor relative to a magnetic field
Magnet, coil & galvanometer to demonstrate or provide component
Microphones, record players, card swiping machines
Induction cooking
Induction hobs
Induction heating
Induction welding
Induction soldering
Induction forging
Induction annealing
Induction brazing
Induction hardening
Induction tempering
Induction curing
Induction sealing
Induction melting
Induction casting
Induction purifying
Induction crystal growing
Induction zone refining
Induction zone melting
Induction zone refining
Induction zone melting
Induction zone refining
Induction zone melting

APPENDIX B

Analysis of Concept Maps using the Six Variables

CM 1

Level	Colour	**No. of scientific concepts**
1	Yellow	4
2	Pink	9
3	Green	2
TOTAL		**15**

Complexity		**Connectedness**	
Width	9	Chunks (C)	6
Depth	3	Crosslinks (CL)	9
HSS	**12**		**15**

CM 2

Level	Colour	**No. of scientific concepts**
1	Yellow	6
2	Pink	17
3	Green	6
4	Blue	2
TOTAL		**31**

Complexity		**Connectedness**	
Width	17	Chunks (C)	9
Depth	4	Crosslinks (CL)	9
HSS	**21**		**18**

CM3

Level	Colour	**No. of scientific concepts**
1	Yellow	7
2	Pink	24
3	Green	15
4	Blue	5
5	Orange	1
TOTAL		**52**

Complexity		**Connectedness**	
Width	24	Chunks (C)	14
Depth	5	Crosslinks (CL)	15
HSS	**29**		**29**

NON-SCIENTIFIC CONCEPTS (NSC)

	CM 1	**CM 2**	**CM 3**
	1 x solve problems	1 x words and pictures…	3 x artefacts
	1 x words and pictures …		1 x not for Gr 11
			2 x magnets, coils & …
TOTAL	**2**	**1**	**6**

NB: Non-scientific concepts and links connected to them were not considered in the analysis of the concept maps above

APPENDIX C

Data Transcription of Concept Maps

Concept Map 1

EMI (core concept) involves:

- Faraday's law, magnetic flux (φ), changing magnetic field (Δφ), and induced current (I).

Faraday's Law (C1):

- Faraday's law relates induced emf to the rate of change of magnetic flux (Δφ/Δt).
- Faraday's law equation is $\varepsilon = -N\Delta\varphi/\Delta t$, where $\varphi = BA$ (CL1)
- $\varepsilon = -N\Delta\varphi/\Delta t$ is used to solve problems involving changing magnetic field

Magnetic flux (C2):

- Magnetic flux is a product of magnetic field strength and cross-sectional area of the enclosed solenoid.
- The magnetic flux equation is $\varphi = BA$.
- Magnetic flux is increasing when the direction of induced magnetic field (CL2) opposes that of the changing magnetic field (CL4).
- Magnetic flux is decreasing when the direction of induced magnetic field (CL3) is the same as that of the changing magnetic field (CL5).

Induced current (C3):

- Induced current produces its own induced magnetic field.
- Direction of the induced current is determined by the Right-hand rule (CL8).

Right-hand rule (C4):

- R-H rule states that the thumb of the right hand points in the direction of the induced field and the curled fingers point in the direction of the induced current.
- R-H rule determines the directions of the induced field (CL6) and induced current.

Changing magnetic field (C5):

- Changing magnetic field produces an induced current (CL7).
- Changing magnetic field is produced by moving a magnet in or out of the solenoid connected to an ammeter.
- Use words and pictures to demonstrate.

NB:

- Not sure if INDUCED MAGNETI FIELD is a chunk or not as a chunk is considered to be linked to at least two other concepts. INDUCED MAGNETIC FIELD HAS two links linked to the SAME concept, i.e. CHANGING MAGNETIC FIELD.
- Total no. of NSCs = 2: (not considered in scorings)
    - NSC1 – solve problems (pink); NSC2 – words and pictures… (green)
    - Corresponding links indicated in dark blue lines (not condidered as links)
- Matches CM1:
    - total no. of concepts = 17; NSCs = 2; total no. of SCs =15 [L1 (yellow) = 4; L2 (pink) = 9; L3 (green) = 2
    - complexity = 12 (HSS) [width = 9 (L2) + depth =3]
    - connectedness = 13 [chunks = 5 + crosslinks = 8]

Concept Map 2

EMI (core concept):

- EMI is a process whereby an emf is induced by a changing magnetic field to produce an induced current (def.)
- EMI is a process that transforms kinetic energy into electrical energy.
- EMI involves magnetic flux (φ), changing magnetic field (Δφ), induced emf (ε) and induced current (I).

C1: Magnetic flux (φ):

- A magnetic flux that increases or decreases is called (CL1) a changing magnetic field/flux (Δφ) (C2).
- Magnetic flux is a magnetic field passing an enclosed area of a conductor perpendiculary (def.2).
- Magnetic flux is a product of magnetic field strength and an area enclosed by a conductor (def.1).
- The magnetic flux equation is φ = BA (C8).
- The magnetic flux is increasing when its direction opposes that of induced magnetic field (CL9).
- Magnetic flux is decreasing when its direction is the same as that of induced magnetic field is (CL8).

C2: Changing magnetic field/flux (Δφ):

- A changing magnetic field produces (CL2) an induced emf (C3).
- Changing magnetic flux is produced by moving a conductor relative to a solenoid connected to a galvanometer.
- Changing magnetic field [process] is applied in microphones, seismographs and card swiping machines.
- Use words and pictures to demonstrate [how a changing magnetic field is used].

C3: Induced emf (ε):

- Induced emf produces (CL3) an induced current (I) (C4).
- Induced emf is voltage produced by a changing magnetic field (def.).
- The magnitude of induced emf is directly proportional to the rate of change of magnetic flux (Δφ/Δt) (Faraday's law).
- Faraday's law equation is ε = -NΔφ/Δt (C7).
- Induced emf direction is indicated by a negative sign in ε = -NΔφ/Δt.

C4: Induced current (I):

- Induced current is a current produced by a changing magnetic field.
- Its magnitude depends on the: strength of magnets, relative motion of magnet and solenoid, number of turns in the solenoid, and angle between the flux and enclosed area of the solenoid.
- Induced current produces its own magnetic field.
- Induced current direction is determined using the R-H rule (C6).

C5: Lenz's law:

- Lenz's law states that the current produced by an emf moves in the direction so that its magnetic field opposes the change in magnetic flux.
- Lenz's law relates the directions of induced current (CL4), induced magnetic field (CL5) and the magnetic flux (CL7)

C6: Right-hand rule

- States that the thumb of right hand points in the direction of induced field and curled fingers in the direction of induced current.
- Used to determine the direction of (CL6) induced magnetic field.

C7: $\varepsilon = -N\Delta\varphi/\Delta t$:
- where $\varphi = BA$ (CL10) and
- N = no. of turns of solenoid.

C8: $\varphi = BA$:
- $\varphi = BA$ is derived from (CL11) def. 1 of magnetic flux.
- Magnetic field strength (B) is the number of flux lines per unit area.

NB:
- Matches CM 2:
    - total no. of concepts = 32; NSC = 1 [words and pitures..(green)]; total no. of SCs = 31 [L1 (yellow) = 6; L2 (pink) = 18; L3 (green) = 5; L4 (blue) = 2
    - complexity = 22 (HSS) [width = 18 (L2) + depth =4]
    - connectedness = 19 [chunks = 8 + crosslinks = 11]
- NSC = 1:
    - not considered when scoring;
    - corresponding links indicated in dark blue lines and not considered when scoring

Concept Map 3

EMI (L1) (Core concept):
- EMI is a process whereby an emf is induced by a changing magnetic field to produce a current (def.).
- EMI is a process where magnetism produces electricity from which magnetic field produces electric current.
- EMI is a process that transforms kinetic energy into electrical energy.
- EMI is applied in transformers, generators and induction stoves.
- EMI involves magnetic flux (C2), changing magnetic field (C3), induced emf (C4) and induced current current (C5).

C1: Magnetic field strength (B) (L3.2):
- Magnetic field strength refers to the number of flux lines per unit area (def.).
- Its equation is $B = \varphi/A$.
- Its SI unit is Tesla (T).
- $1T = 1Wb.m^{-2}$

C2: Magnetic flux (φ) (L3.1):
- Magnetic flux is a magnetic field linking the enclosed area of a conductor perpendicularly (def.2).
- Magnetic flux is a product of magnetic field strength and the enclosed area of a conductor (def.1).
- Magnetic flux equation is $\varphi = BA$ for $B \perp A$.
- Magnetic flux equation is $\varphi = BA\cos\theta$.
- $\varphi = BA\cos\theta$ is not for Grade 11 (NSC 6).
- Magnetic flux is increasing (C13) when its direction opposes that of (CL14) induced magnetic field.

- Magnetic flux is decreasing (C14) when its direction is the same as that of (CL15) induced magnetic field.
- Use artefacts to explain magnetic flux (NSC 1).
- Magentic flux that increases or decreases produces (CL2) a changing magnetic field/flux (C3).
- The magnitude of magnetic flux depends on the area enclosed by the conductor and the magnetic field strength (CL1).
- The SI unit is Weber (Wb).
- $1Wb = 1T.m^2$.

C3: Changing magnetic field/flux ($\Delta\varphi$) (L3.3):
- Changing magnetic field produces (CL3) an induced emf (C4)
- Changing magnetic field equations are: $\Delta\varphi = \Delta BA$, $\Delta\varphi = (B_f - B_i)A$ and $\Delta\varphi = (\varphi_f - \varphi_i)$.
- Changing magnetic field is produced by moving a conductor relative to a magnetic field.
- Use magnets, coils and galvanometers to demonstrate or provide groupwork (NSC 5).
- Use artefacts [to explain relative motion] (NSC 4).
- Applied in microphones, seismographs and card swiping machines.

C4: Induced emf (ε) (L4):
- Induced emf produces (CL4) induced current (C5).
- Induced emf is voltage produced by a changing magnetic field.
- Its SI unit is Volt (V).
- $IV = 1Wb.s^{-1} = 1T.m^2.s^{-1}$.
- Its magnitude depends on the rate of change of magnetic flux ($\Delta\varphi/\Delta t$) and the number of turns in the coil (N).
- Relation of induced magnetic field and the rate of change of magnetic flux lead to Faraday's law.

C5: Induced current (I) (L2):
- Induced current is current produced by a changing magnetic field.
- Its magnitude depends on the: strength of magnets, relative motion of magnet and solenoid, number of turns in the solenoid, and angle between the flux and enclosed area of the solenoid.
- Use magnets, coils and galvanometers to demonstrate or provide groupwork [on how these factors influence magnitude] (NSC 2).
- Induced current produces its own magnetic field.
- Induced current direction is determined using the R-H rule (C7).

C6: Lenz's law:
- Lenz's law states that the current produced by an emf moves in the direction so that its magnetic field opposes the change in magnetic flux.
- Lenz's law relates the directions of induced current (CL5), induced magnetic field (CL6) and the magnetic flux (CL7)

C7: Right-hand rule:
- States that the thumb of right hand points in the direction of induced field and curled fingers in the direction of induced current.
- Used to determine the direction of (CL8) induced magnetic field.
- The method of finding the directions of I, φ and induced field is as follows:
    - determine if flux is increasing, decreasing or unchanged.
- Use artefacts (NSC 3)

C8: Rate of change of magnetic flux ($\Delta\varphi/\Delta t$):

- Relationship between $\Delta\varphi/\Delta t$ and ε leads to Faraday's law (C9).
- The product of $\Delta\varphi/\Delta t$ and N contributes to Faraday's equation.

C9: Faraday's law:

- States that the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux.
- Faraday's law equation is (CL9) $\varepsilon = -N\Delta\varphi/\Delta t$ (C10).

C10: $\varepsilon = -N\Delta\varphi/\Delta t$:

- Negative sign shows that the direction of ε opposes that of φ.
- $\varepsilon = IR$ (Ohm's law)
- where $\varphi = BA$ and $\varphi = BA\cos\theta$
- where $\Delta\varphi = \Delta BA$, $\Delta\varphi = (B_f - B_i)A$ and $\Delta\varphi = (\varphi_f - \varphi_i)$ (CL13).

C11: Solving strategy, unit conversions and area formulae:

- Maths requirements for (CL10) $\varepsilon = -N\Delta\varphi/\Delta t$.
- Maths requirements for (CL12) $\Delta\varphi = \Delta BA$, $\Delta\varphi = (B_f - B_i)A$ and $\Delta\varphi = (\varphi_f - \varphi_i)$.
- Maths requirements for (CL11) $\varphi = BA$ and $\varphi = BA\cos\theta$.

C12: $\varphi = BA$:

- $\varphi = BA$ is derived from def. 1 of magnetic flux.
- $\varphi = BA$ for $B \perp A$.

C13: Increasing magnetic flux:

- Magnetic flux is increasing when a magnet moves toward a coil.
- Magnetic flux is increasing when its direction opposes that of (CL14) induced magnetic field.

C14: Decreasing magnetic flux:

- Magnetic flux is decreasing when a magnet moves away from a coil.
- Magnetic flux is decreasing when its direction is the same as that of (CL15) induced magnetic field.

NB:

- Matches CM 3:
    - total no. of concepts = 59; NSC = 6; total no. of SC = 53 [L1 (yellow) = 8; L2 (pink) = 24; L3 (green) = 14; L4 (blue) = 6; L5 (orange) = 1]
    - complexity = 29 (HSS) [width = 24 (L2) + depth =5]
    - connectedness = 29 [chunks = 14 + crosslinks = 15]
- NSC = 6:
    - 4 (green); 1 (pink); 1(orange)
    - not considered when scoring;
    - corresponding links indicated in dark blue lines and not considered when s

APPENDIX D

Summary Sheet

Typology: Content Knowledge

EMI (CORE CONCEPT):

- A process whereby an emf is induced by a changing magnetic field to produce current.
- A process in which magnetism produces electricity.
- A process that transforms kinetic energy into electrical energy.

- A process applied in transformers, generators and induction stoves.
- A process that involves concepts such as magnetic flux, changing magnetic field, magnetic field strength, induced current, induced emf and induced magnetic field.

MAGNETIC FIELD STRENGTH (B):
- Refers to the number of flux line per unit area.
- Equation is $B = \varphi/A$.
- SI unit is Tesla (T).
- $1T = 1Wb.m^{-2}$.

MAGNETIC FLUX (φ):
- A magnetic field passing/linking the area enclosed by a conductor perpendicularly.
- A product of magnetic field strength and the area enclosed by a conductor.
- Equations are: $\varphi = BA$ for $B \perp A$ and $\varphi = BA\cos\theta$ for B not $\perp$ A.
- SI unit is a Weber (Wb).
- $1Wb = 1T.m^2$.
- An increasing or decreasing magnetic flux is referred to as a changing magnetic field/flux ($\Delta\varphi$).
- A magnetic flux is increasing when its direction opposes that of an induced magnetic field.
- A magnetic flux is decreasing when its direction is the same as that of an induced magnetic field.
- A magnetic flux is increasing if a magnet moves towards a coil.
- A magnetic flux is decreasing if a magnet moves away from a coil.

CHANGING MAGNETIC FIELD/FLUX ($\Delta\varphi$):
- A changing magnetic field produces an induced emf.
- Produced by moving a magnet relative to a conductor.
- Applied in microphones, seismographs and induction stoves.
- Equations are: $\Delta\varphi = \Delta BA = (B_f - B_i)A = (\varphi_f - \varphi_i)$.

INDUCED EMF (ε):
- An induced emf produces an induced current.
- Voltage produced by a changing magnetic field.
- Faraday's law relates the induced emf to the rate of change of magnetic flux.
- Faraday's law states that the magnitude of emf is directly proportional to the rate of change of magnetic flux.
- Equation: $\varepsilon = -N\Delta\varphi/\Delta t$ (Faraday's law) and $\varepsilon = IR$ (Ohm's law).
- Negative sign in equation indicates that the direction of ε opposes that of $\Delta\varphi$.
- SI unit is volt (V).
- $1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$.

INDUCED CURRENT (I):
- Current produced by a changing magnetic field.
- Magnitude depends on the: strength of magnet, relative motion of magnet and coil, number of turns in coil, and angle between the flux and enclosed area of the coil.
- Produces its own induced magnetic field.
- Directions of induced current and induced magnetic field determined by R-H rule.
- R-H rule states that the thumb of the right hand points in the direction of the induced field and the curled fingers point in the direction of induced current.
- Method of finding the directions of I, φ and ε:
    - Determine if φ is increasing, decreasing or unchanged;
    - Then use R-H rule.

INDUCED MAGNETIC FIELD:

- Is produced by an induced current.
- Its direction always opposes that of changing magnetic field.
- Both the R-H rule and Lenz's law can be used to determine its direction.

LENZ'S LAW:

- Relate the directions of induced current, induced magnetic field and changing magnetic field/flux.
- States that the current produced by an emf moves in the direction so that its magnetic field opposes that of the change of magnetic flux.

Typology: Instructional Delivery

1. $\varepsilon = -N\Delta\varphi/\Delta t$ used to solve problems involving changing magnetic field.
2. use words and pictures to demonstrate [how magnetic field produces current].
3. changing magnetic field is applied in transformers, generators and induction stoves.
4. L1; L2; L3.1; L3.2; L3.3 and L4 to represent the sequence of lessons.
5. $\varphi = BA\cos\theta$ not for Grade 11.
6. use artefacts to explain magnetic flux.
7. a changing magnetic field is produced by moving a magnet relative to a conductor (coil or solenoid).
8. A changing magnetic field is applied in microphones, seismographs and card swiping machines.
9. use magnets, coils and galvanometers to demonstrate or provide groupwork.
10. maths requirements: solving strategy, unit conversions and area formulae.

APPENDIX E

Classification of Concepts of the three Concept Maps

Category 1: Main concepts of EMI
1. magnetic field strength (B)
2. magnetic flux/field (φ)
3. changing magnetic field/ flux ($\Delta\varphi$)
4. induced emf (ε)
5. induced magnetic field (ind. φ)
6. induced current (ind. I)

Category 2: Laws, Rules and Principles
1. Faraday's law
2. Lenz's law
3. Ohm's law
4. Right-hand rule
5. EMI principle

Category 3: Definitions of concepts
1. an emf is induced by a changing magnetic field to produce a current (EMI)
2. number of fluxs per unit area (B)
3. magnetic field linking an enclosed area of a conductor perpendicularly (φ)
4. product of magnetic field strength and the enclosed area of a conductor (φ)
5. voltage produced by a changing magnetic field (ε)
6. current produced by a changing magnetic field (ind. I)

Category 4: Equations
1. $\varphi = BA$ ($B \perp A$); $\varphi = BA\cos\theta$ (B not $\perp A$)
2. $\Delta\varphi = \Delta BA$; $\Delta\varphi = (B_f - B_i)A$; $\Delta\varphi = (\varphi_f - \varphi_i)$
3. $\varepsilon = -N\Delta\varphi/\Delta t$; $\varepsilon = IR$

Category 5: Units of measurement
1. Tesla (T) ; $1T = 1\ Wb.m^{-2}$
2. Weber (Wb); $1Wb = 1T.m^2$
3. Volt (V); $1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$

Category 6: Factors influencing the magnitude of concepts
1. induced current: strength of magnet; relative motion of magnet and solenoid; number of turns in solenoid; angle between flux and enclosed area of conductor.
2. induced emf: rate of change of magnetic flux

Category 7: Direction of main concepts
1. negative sign in Faraday's law equation: direction of ε opposes that of $\Delta\varphi$
2. method of finding direction of I, φ,$\Delta\varphi$, & ε: determine if φ is increasing, decreasing or unchanged then use R-H rule or move a magnet relative to conductor (towards of away from).

Category 8: EMI process
1. magnetism produces electricity
2. magnetic field produces electric current
3 kinetic energy is transformed into electrical nergy

Category 9: Teaching aspects
1. solve problems
2. words & pictures to demonstrate
3. magnets, coils & galvanometers to demonstrate or provide groupwork
4. artefacts to explain
5. transformers, generators & induction stoves
6. microphones, seismographs & card swiping machines
7. soving strategy, unit conversions, area formulae
8. not for Grade 11
9. L1, L2, L3.1, L3.2, L3.3 & L4

APPENDIX F

Grade 11 Curriculum on EMI

Electromagnetism:	**Core knowledge and concepts**	**Comments and links**
• Magnetic field associated with current;	• Provide evidence for the existence of a magnetic field near a current carrying wire. • Use the Right Hand Rule to determine the magnetic field associated with: (I) a straight current carrying wire, (ii) a current carrying loop of wire and (iii) a solenoid.	A simple form of evidence for the existence of a magnetic field near a current carrying wire is that a compass needle placed near the wire will deflect (link to Grade 10). Try to give learners the opportunity to observe this.
• Current induced by changing magnetic field	• State Faraday's Law. • Use words and pictures to describe in words and pictures what happens when a bar magnet is pushed into or pulled out of a solenoid connected to an ammeter. • 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. • Calculate the induced emf and induced current for situations involving a changing magnetic	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

	field using the equation for Faraday's Law: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ where ϕ=BA is the magnetic flux.	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.
• Transformers;	• Draw a sketch of the main features of a transformer • Use Faraday's Law to explain how a transformer works in words and pictures. • Use the equation for Faraday's Law to derive an expression involving the ratio between the voltages and number of windings in the primary and secondary coils. • Use the expression $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ to perform calculations for transformers with various specifications. • State the difference between a step up and a step down transformer in both structure and function. • Give an example of the use of transformers	The essential features of a transformer are two coils of wire, called the primary and the secondary, which are wound around different sections of the same iron core. When an alternating voltage is applied to the primary coil it creates an alternating current in that coil, which induces an alternating magnetic field in the iron core. This changing magnetic field induces an emf, which creates a current in the secondary coil. Transformers are very important in the supply of electricity nationally. In order to reduce energy losses due to heating, electrical energy is transported from power stations along power lines at high voltage and low current. Transformers are used to step the voltage up from the power station to the power lines, and step it down from the power lines to buildings where it is needed.
• Motion of a charged particle in a magnetic field.	• State that when a charged particle moves through a magnetic field it experiences a force. • Use the equation F=qvB to calculate the force exerted on a charge that moves at right angles to a magnetic field. • Use the Right Hand Rule to determine the direction of the force. • Explain how this effect is used in a television	To use the Right Hand Rule to find the direction of the force the magnetic field exerts on the moving charge, point your fingers in the direction of the velocity of the charge and turn them (as if turning a screwdriver) towards the direction of the magnetic field. Your thumb will point in the direction of the force. If the charge is negative, the direction of the force will be opposite to the direction of your thumb. By only using the Right Hand Rule in the NCS learners are less likely to get confused than when there are different rules to remember. For learners who study Physics after school, they will be well prepared to deal with vector cross products.

APPENDIX G

A CoRe ON EMI

BIG IDEAS				
PROMPTS	**A changing magnetic field induces an emf that causes an electric field to set up an induced current in the conductor**	**The induced current moves in a direction so that its magnetic field opposes the changing magnetic field that produced it**	**It is the relationship between the induced emf and the rate of change of magnetic flux that drives the process of EMI and hence the generation of electric current**	**A changing current in one conductor induces an emf which sets up an induced current in a nearby conductor**
1. What do you intend learners to learn about this idea?	• The relative motion of a conductor and a magnetic field produces an electric	• There are two magnetic fields involved in the EMI process: the changing magnetic field that induces	• EMI concepts: induced emf; magnetic flux; magnetic field strength; rate of change of flux;	• The changing magnetic field produced by an ac or dc voltage applied to the primary coil induces an ac or voltage in the

	current; • The EMI process involves concepts such as changing magnetic field, induced emf, electric field and induced current; • The vector nature of these concepts have an effect on the current induced; • Factors influencing the magnitude of induced current; • Factors which influences the direction of the induced current; • The first principle of the EMI process and its application.	current and the magnetic field produced by the induced current; • The induced current produces its own magnetic field that opposes the changing magnetic field that has produced it (Lenz's law); • The direction of the induced current and its associated magnetic field can be found using the Right Hand Rule; • It is the interaction of these magnetic fields that results in magnetic force; • The EMI process also involves the induced magnetic field concepts.	• Definitions of each of the concepts; • Factors infuencing the magnitude of these concepts; • The directional nature of the concepts; • The units associated with the concepts; • Equations of each of the concepts and their applications; • Faraday's law of EMI and its implications; • The relationships amongst these concepts; • The relationship between Faraday's law and Ohm's law.	secondary coil respectively; • The ratio of the voltages of coils linked to the same magnetic flux is proportional to the ratio of the number of turns in the coils and inversely proportional to the ratio of the currents in them.
2. Why is it important for learners to know this?	• Electricity and magnetism coexist; • Electrical energy can be generated by other means besides electrostatics and electric circuits; • Kinetic energy can be transformed into electrical energy; • Devices such as microphones and seismographs use this principle to produce electricity.	• Read/write (playback/recording) heads for tape or disk recorders and credit card swiping machines use the principle of opposing magnetic fields to generate electric signals.	• Generators and alternators use the principle of electromagnetic induction to produce electricity.	• Transformers, induction stoves and ignition systems of automobiles use the principle of mutual induction to transmit electricity; • The National Grid System operate on the principle of mutual induction
3. What else you	• The induced	• There is a difference	• A changing magnetic	

	know about this idea (that you do not intend learners to know yet)?	current has an associated magnetic field that opposes the changing magnetic field that has produced it; •The second principle of EMI process;	between a magnetic field and magnetic flux; • It is the rate of change of magnetic flux that induces current.	flux can be produced by an ac or dc power supply; • How generators work – grade 12.	
4.	**Difficulties/ limitations connected with teaching this idea**	• Learners regard magnetic field lines as real entities; • Confusion between electric and magnetic effects; • Most of EMI ideas can only be better explained using laboratoty equipment; • Learners associate electric current with an emf induced by the source of emf like a battery or generator only; • EMI phenomena not being obvious part of learners' everyday discourse.	• The induced field is in opposite direction to the field that induces it rather than the change in the ukfield inducing it; • Learners believe there must always be contact between magnetic field and conductor for emf to be induced; • Most textbooks use 2-dimensional representations of EMI phenomena instead of 3-dimensions;	• Difference between potential difference and induced emf; • Inability to distinguish between 'change of' and 'rate of change of' magnetic field; • Mathematical skills required to solve EMI problems.	• Induced current is proportional to the change in current rather than the rate of change of current; • Direct use of Ohm's law.
5.	**Knowledge about learners' thinking that influences your teaching of this idea**	• Electric current has an associated magnetic field; • The strength of current is proportional to the strength of the field.	• For every action there is an equal but opposite reaction (Newton's 3rd law);	• Concepts of change, rate and magnetic fields; • Mathematical skills required to solve EMI problems.	• Electricity is transmitted through the National Grid System; • Difference between ac and dc power supply.

6. Other factors that influence your teaching of this idea	• Learners know microphones but do not understand the scientific principle behind its working; • Learners need to know about the laboratory apparatus used in EMI to develop conceptual understanding of the topic.	• Learners know tapes, disks and credit cards but do not understand the scientific principle(s) behind their working.	• Learners know generators and alternators but do not understand the scientific principle behind their working.	• Learners know transformers, induction stoves and ignition systems but do not understand the scientific principles behind their working.
7. Teaching procedures (and particular reasons for using these to engage with this idea).	• Practical activity to observe the phenomenon; • Group-work for gathering data; • Question-and-answer approach to link new and existing knowledge; • Class-discussion for evaluating and summarising the main points of the lesson.	• Use diagrams to explain the existence of the two fields and the directions of induced current and its associated field; • Question-and-answer approach to link new and existing knowledge;	• Use diagrams to explain the existence of the two fields and the directions of induced current and its associated field; • Question-and-answer approach to link new and existing knowledge;	• Practical activity to observe the phenomenon; • Use diagrams to explain the existence of the two fields and the directions of induced current and its associated field; • Question-and-answer approach to link new and existing knowledge;
8. Specific ways of ascertaining learners' understanding or confusion around this idea (include likely range of responses).	• Provide time for learners to ask questions; • Class-activity to ascertain their understanding ; • Home-activity to link new knowledge with outside-the-classroom knowledge.	• Provide time for learners to ask questions; • Class-activity to ascertain their understanding; • Home-activity to link new knowledge with outside-the-classroom knowledge.	• Provide time for learners to ask questions; • Class-activity to ascertain their understanding; • Home-activity to link new knowledge with outside-the-classroom knowledge.	• Provide time for learners to ask questions; • Class-activity to ascertain their understanding; • Home-activity to link new knowledge with outside-the-classroom knowledge.

APPENDIX H

Lesson Plans

LESSON PLAN 1

PHYSICAL SCIENCES **GRADE: 11**
TOPIC: INTRODUCTION TO EMI **TIME: 1 HOUR**

ACTIVITY	OUTLINE	KEY POINTS	LTSM
Introduction (± 5 minutes)	• Teacher introduces topic by discussing work covered in previous lessons; • Focus questions: Can magnetism cause electricity? Can kinetic energy be transformed into electric energy?	• An electric current or moving charge produces a magnetic field; • The interaction of magnetic fields produce a force; • Force causes motion; • Electricity produces magnetism; • Electrical energy is converted into kinetic energy.	• Chalkboard: summary and concept map
Group-Work (± 20 minutes)	• Teacher explains instructions and apparatus of the practical activity; • Learners work in groups to observe what happens when the N-pole of the magnet is moved into the coil, held still and then moved out; • Teacher moves around observing and assisting learners who need assistance.	• No current flows when the coil and the magnet are stationary; • Current flows when the coil and magnet are moved relative to each other; • The direction of current depends on the movement of the magnet relative to the coil;	• Galvanometer, two strong bar magnets, two coils of wire with different number of turns; • Activity Worksheet 1.
Report back (± 10 minutes)	• Teacher provides feedback by discussing worksheet with learners.	• A moving or changing magnetic field sets up an induced emf in the coil which produces an induced current.	• Activity worksheet; • Chalkboard
Class discussion (± 25 minutes)	• Teacher discusses with learners: - how an induced current is produced; - the definition of EMI; - ways of achieving EMI - applications of EMI: microphone and seismograph.	• Moving a conductor relative to a magnet changes the magnetic field (flux) in the area enclosed by the conductor (coil or solenoid); • The changing magnetic flux sets up an induced emf that produces an induced current in the conductor; • To produced an induced current you need: (1) a closed conductor, and (2) an external changing magnetic flux; • EMI is the creation of an emf in the conductor by changing the magnetic field (flux) linking with the conductor to set up an induced current; • EMI can be achieved by: (i) moving the conductor relative to the magnetic field; (ii) alternating the current in the primary circuit linked to the secondary circuit with a soft iron	• Chalkboard; • OHP • Transparencies of: (i) summary of lesson; (ii) diagrams of microphone and seismograph; (iii) dc transformer

		core; • EMI is a process whereby: (i) magnetism produces electricity; (ii) kinetic energy is transformed into electrical energy • The principle of EMI is used in microphones and seisomograph.	
Home-Activity			• Worksheet 1

REFLECTIONS:
• Try a bulb connected to the coil and move a magnet in and out of the coil to find out if the bulb would light.

LESSON PLAN 2

PHYSICAL SCIENCES **GRADE: 11**
TOPIC: INDUCED CURRENT **TIME: 1½ HOUR**

ACTIVITY	OUTLINE	KEY POINTS	LTSM
Introduction (± 5 minutes)	• Teacher introduces topic by discussing work covered in previous lesson; • Focus questions: to investigate factors influencing the magnitude and direction of current	• Relative motion of magnet and coil → changing magnetic field → induced emf → induced current in the coil; • Induced current is produced by a changing magnetic field; • Requirements for an induced current: (i) a changing magnetic field; (ii) a closed condutor • Induced current is a vector quantity	• Chalkboard: summary and concept map
Group-Work (± 20 minutes)	• Teacher explains instructions and apparatus of the practical activity; • Learners work in groups to observe what happens when: (i) relative motion of the magnet and coil is changed, (ii) the strength of magnet is changed and (iii) the no. of turns in the coil is changed; • Teacher moves around observing and assisting learners who need assistance.	• The magnitude of induced current depends on: - the relative motion of magnet and coil; - the strength of the field around the magnet; - the no. of turns in the coil. • The direction of current depends on the direction of the relative movement between the magnet and coil.	• Galvanometer, two strong bar magnets, two coils of wire with different number of turns; • Activity Worksheet 2.
Report back (± 10 minutes)	• Teacher provides feedback by discussing worksheet with learners.	• Factors influencing the magnitude and direction of the induced current	• Activity worksheet 2; • Chalkboard
Class discussion (± 45 minutes)	• Teacher discusses with learners: - the definition of induced current; - the requirements for current to be induced; - the vector nature of induced current; - factors influencing the magnitude of induced current; - method of determining the direction of induced current:	• Induced current is current produced by a changing magnetic field; • Requirements: (i) a changing magnetic field; (ii) a closed conductor; • Induced current is a vector quantity, i.e. has both magnitude and direction;	• Chalkboard; • OHP • Transparencies of: (i) summary of lesson; (ii) diagrams of magnets moved in and out of coils;

	- the Lenz's law	• The magnitude depends on: (i) speed of magnet relative to coil; (ii) strength of magnet; (iii) no. of turns in the coil; and (iv) angle between magnet and area enclosed by the coil; • Method of determining the direction of induced current: (i) Determine if the magnetic field is increasing, decreasing or unchanged; (ii) Use R-H solenoid rule to determine current direction • Field is increasing if: (i) magnet is moved towards coil; (ii) the changing and induced fields point in opposite directions; • Field is decreasing if: (i) magnet is moved away from coil: (ii) the changing and induced fields point in the same direction; • The induced current produces its own magnetic field that opposes that of the changing magnetic field; • A current induced by an emf moves in a direction so that its magnetic field opposes that of a changing magnetic field (Lenz's law); • An increasing field causes repulsion whereas a decreasing field causes attraction (magnetic forces).	
Class-Activity (±10 minutes)	• Learners determine the directions of the induced magnetic field and induced current of the S-pole: (i) moved towards the coil; and (ii) moved away from the coil.		
Home-Activity			• Worksheet 2

REFLECTIONS:
• Maybe I should have allowed learners to use the apparatus to test the direction of current when opposite poles of magnets are moved in and out of the coil;

LESSON PLAN 3

PHYSICAL SCIENCES **GRADE: 11**
TOPIC: MAGNETIC FLUX **TIME: ½ HOUR**

ACTIVITY	OUTLINE	KEY POINTS	LTSM
Introduction (± 5 minutes)	• Teacher uses a concept map to introduce the topic; • Focus question: What is a magnetic flux?	• Relative motion of magnet and coil causes a changing magnetic field; • A changing magnetic field sets up an induced emf in the coil; • An induced emf sets up an induced current in the coil; • The induced current sets up its own magnetic field that opposes the changing magnetic field.	• Concept map
Class discussion (± 25 minutes)	• Teacher discusses with learners: - Ways of defining magnetic flux; - The equation of magnetic flux; - The units of magnetic flux - Factors influencing the vector nature of the flux; - The equation for the changing flux;	• Magnetic flux: - Magnetic field that cuts the enclosed area of a conductor perpendicularly; - Total number of field lines passing perpendicularly through the area enclosed by the conductor; - Product of magnetic field strength and the area enclosed by the conductor; - Equations: $\Phi = BA$; $\Delta\Phi = \Delta BA$ - SI unit: weber (Wb); $1Wb = 1T.m^2$; - Factors influencing the magnitude: (i) magnetic field strength and (ii) the area enclosed by the conductor; - The direction of flux is the same as that of the magnetic field strength; • Magnetic field strength: - Total number of flux lines per unit area; - Equation: $B = \Phi/A$ - SI unit: tesla (T); $1T = 1Wb.m^{-2}$	• Chalkboard

REFLECTIONS:
• I should have given two examples of how to apply the equations to EMI problems;
• I should have also provided a worksheet to assess their understanding of the topic;

LESSON PLAN 4

PHYSICAL SCIENCES **GRADE: 11**
TOPIC: INDUCED EMF **TIME: 1 HOUR**

ACTIVITY	OUTLINE	KEY POINTS	LTSM
Introduction (± 2 minutes)	• Teacher uses a concept map to introduce the topic; • Focus question: What is an induced emf?	• EMI is a process whereby an emf is created by changing magnetic field to induce a current in a conductor.	• Concept map
Class discussion (± 13 minutes)	• Teacher discusses with learners: - The definition of induced emf; - Faraday's law of EMI; - Faraday's law equation; - The vector nature of the induced emf; - The units of induced emf; - Application of $\Phi = BA$ and $\varepsilon = -N\Delta\Phi/\Delta t$ to solve EMI problems (use examples in their textbooks);	• P.d. or voltage produced by a changing magnetic flux; • Faraday's law: the magnitude of the induced emf is directly proportional to the rate of change of flux; • Equation: $\varepsilon = -N\Delta\Phi/\Delta t$ • Factors influencing the magnitude of ε: (i) rate of change of flux and (ii) the number of turns in the conductor; • Negative sign indicate that the direction of ε is always opposite to that of $\Delta\Phi$; • SI unit: volt (V); $1V = 1Wb.s^{-1} = 1T.m^2.s^{-1}$;	• Chalkboard; • Textbooks; • Transparency of problems to solve;
Group-work (±5 minutes)	• Learners do problem 2 from the transparency.		
Class discussion (±40 minutes)	• Teacher discusses with learners: - Solutions of problem 2; - The importance of the two equations; - The strategy for solving EMI problems; - Mathematical issues involved when using these equations; - Other related equations.	• $\Phi = BA$ and $\varepsilon = -N\Delta\Phi/\Delta t$ can be used to: - Define EMI concepts; - Identify factors that influence EMI concepts; - State Faraday's law; - Identify relationship between concepts. • Strategy for solving EMI concepts: (i) write data; (ii) choose formula; (iii) substitute; and (iv) solve for answer. • Mathematical issues: (i) area formula; (ii) unit conversions • Substitute $\Delta B = B_f - B_i$ and $\Delta\Phi = \Phi_f - \Phi_i$ in $\Delta\Phi = \Delta BA$ and $\varepsilon = -N\Delta\Phi/\Delta t$ to derive other related equations	• Transparency of summary
Home-activity			• Worksheet 3

REFLECTIONS:

APPENDIX I

Class Practical Activities and solutions

ELECTROMAGNETIC INDUCTION

Name of Learner: _____ Date: _____
Names of Group Members: 1. _____ 4. _____
(Surname & initials only) 2. _____ 5. _____
3. _____ 6. _____

ACTIVITY 1

Time allocation: 20 minutes

Instructions

- Work in groups to perform the experiment and answer Questions 1 and 2.
- Each group member should however answer Questions 3 to 6 individually.

Task

Use the apparatus provided to observe what happens to a galvanometer needle (magnitude and direction of the needle) when the N-pole of the magnet is:

- moved into the coil;
- held stationary inside the coil;
- moved out of the coil.

Questions

1. Complete each of the following statements:

   When the N-pole of the magnet is moved into the coil, the needle **deflects** to the **right**.
   When the N-pole of the magnet is held still inside the coil, the needle **remains stationary/does not move.**
   When the N-pole of the magnet is moved out of the coil, the needle **deflects** to the **left.**

2. What deductions can be drawn from the above observations?

2.1 The needle **remains stationary** when the magnet is held still inside the coil;
2.2 The needle **deflects** every time there is movement of the magnet;
2.3 The direction of the **needle** depends on the direction of the movement of the magnet.

3. Give a brief explanation of what you think is happening in this investigation.

3.1 A magnet is surrounded by a (1) **magnetic field**.
3.1.1 A moving (1) **magnetic field** sets up an (2) **induced emf** which produces an electric field in the coil.
3.2 This electric field causes the (3) **electric charges** in the coil to move.
3.3 The movement of (3) **electric charges** is referred to as (4) an **electric current**.

3.3.1 The direction of (4) **the electric current** depends on the direction of the movement of the (1) **magnetic field**.

4. What conclusion can be drawn from this investigation?

A **moving** (1) **magnetic field** sets up an **induced** (2) **emf** in the coil which produces an **induced** (4) **electric current**.

ELECTROMAGNETIC INDUCTION

Names of Group Members: 1. _____ 4. _____
(Surname & initials only) 2. _____ 5. _____
3. _____ 6. _____
Date: _____

ACTIVITY 2

Time Allocation: 20 minutes

Instructions

Use the apparatus provided to observe what happens to a galvanometer needle when:

- The N-pole of the magnet is moved slowly in and out of the coil;
- The N-pole of the magnet is moved faster in and out of the coil;
- Both the magnet and the coil are moved at the same speed towards each other;
- Two magnets instead of one are used;
- A coil with a more number of turns is used;

Questions

1. Circle the **bold** word that makes each of the following statements correct:

Moving the magnet slowly in and out of the coil causes the needle to deflect **slightly**/**greatly** in **same**/**opposite** directions.
Moving the magnet faster in and out of the coil causes the needle to deflect **slightly**/**greatly** in **same**/**opposite** directions.
Moving both the magnet and the coil at the same speed towards each other causes the needle to deflect **slightly**/**greatly**.
Using two magnets instead of one cause the needle to deflect **slightly**/**greatly**.
Using a coil with more number of turns causes the needle to deflect **slightly**/**greatly**.

2. Circle the **bold** word that makes each of the following statements correct:

2.1 The slower the movement of the magnet into the coil, the **smaller**/**larger** is the current in the coil.
2.2 The faster the movement of the magnet into the coil, the **smaller**/**larger** is the current in the coil.
2.3 Moving both the magnet and coil at the same speed produces a **smaller**/**larger** current in the coil.
2.4 Using two magnets instead of one produces a **smaller**/**larger** current in the coil.
2.5 Using a coil with more number of turns produces a **smaller**/**larger** current in the coil.

3. Complete each of the following statements by filling in the missing words.

It is the **change in/relative** motion of the magnetic field and the coil that produces an induced current.

The magnitude of the induced current depends on:
the **speed** of the moving magnetic field relative to the coil;
the **strength** of the magnetic field;
the **number of turns** in the coil;
the **angle** between the enclosed surface area of the coil and the magnetic field.

The direction of the induced current depends on the direction of the **magnetic field** relative to the coil.

The induced current is a vector quantity because it has **magnitude** and **direction**.

APPENDIX J

Test and Memorandum

PHYSICAL SCIENCES TEST

ELECTROMAGNETIC INDUCTION **MARK: 85**
GRADE 11 **TIME: 1½ HOURS**
LOs: 1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 3.1

INSTRUCTIONS

1. Answer all the questions.
2. Number the questions correctly according to the numbering system used in this question paper.
3. Wherever explanation or discussion is required, be brief and to the point.
4. Non-programmable calculators may be used.
5. A data sheet with formulae is provided at the back of the question paper.

SECTION A

QUESTION 1

Write only the word/term for each of the following statements next to the question numbers (1.1 – 1.5).

1.1 A process in which an emf is created by moving a magnet relative to the conductor. (1)
1.2 A field that induces an emf that produces an induced current. (1)
1.3 A unit equivalent to a tesla square metre. (1)
1.4 The total number of magnetic field lines per unit area. (1)
1.5 A device used to alter or change the voltage of an alternating current. (1)
[5]

QUESTION 2

Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the corresponding question number (2.1 - 2.5). If the statement is FALSE, write down the correct statement.

2.1 An emf produced when a magnet moves relative to a coil is set up by a battery. (2)
2.2 The magnetic flux is decreasing if two magnetic fields point in the same direction. (2)
2.3 The magnitude of the magnetic flux is at maximum when the surface of the coil is parallel to the magnetic field. (2)
2.4 A step-up transformer increases the induced current and decreases the voltage. (2)

2.5 The ratio of the voltages across the coils in a transformer is directly proportional to the ratio of the currents and indirectly proportional to the number of turns in each coil. (2)

[10]

QUESTION 3

3.1 Which one of the following is the correct unit for emf?

A. T.m C. $T.m^2.s^{-1}$

B. $T.m^2$ D. $T.m.s^{-2}$ (2)

3.2 A coil with an enclosed area of $3x10^{-5}$ m^2 experiences a change in magnetic flux of $1,5x10^{-5}$ $T.m^2$. The magnetic field strength linking with the coil is _____.

A. 0,5 units of field strength C. 1,5 units of field strength

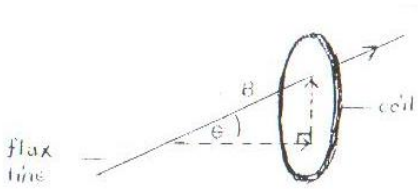
B. 2,0 units of field strength D. 4,5 units of field strength (2)

3.2 The induced emf through a coil with 5 turns is 30V. The rate of change in Magnetic flux is _____ greater than that of the same coil with 1 turn.

A. 0,03 C. 5

B. 0,17 D. 6 (2)

3.4 Consider a magnetic field line that cuts a coil as shown in the diagram below.



The magnetic flux that produces a maximum magnetic field strength can be determined by:

A. BA C. BAcosθ

B. BAsinθ D. BAtanθ (2)

3.5 The current flowing in a primary coil of a transformer can induce a current in a secondary coil:

A. only when the voltage increases

B. only when the current increases

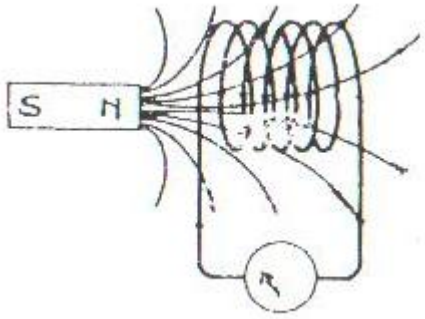
C. when the current is constant

D. only when the direction of current is reversed. (2)

[10]

QUESTION 4

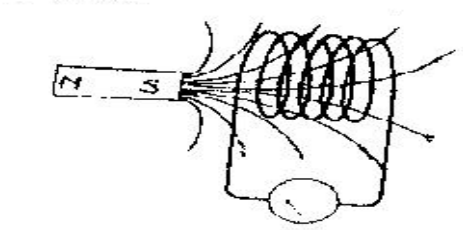
During a practical session, Ayanda and Kgomotso investigated the effect of moving a magnet relative to a coil. They connected a coil to a galvanometer and then moved the N-pole of the magnet into the coil, held it stationary inside the coil and moved it out. The diagram below shows the set up of their experiment.



4.1	Formulate an investigative question for this experiment.	(2)
4.2	Formulate a hypothesis for this investigation.	(2)
4.3	Write down each of the following variables for this investigation:	
4.3.1	independent variable	(1)
4.3.2	dependent variable	(1)
4.4	What happens to the galvanometer needle:	
4.4.1	at the instant the magnet is moved?	(1)
4.4.2	when the magnet is held stationary inside the coil.	(1)
4.5	What conclusion can be made with regards to the observations obtained in Question 4.4 above.	(3)
		[11]

QUESTION 5

Mpho inserts a S-pole of a magnet in a coil connected to a galvanometer as shown in the diagram below.



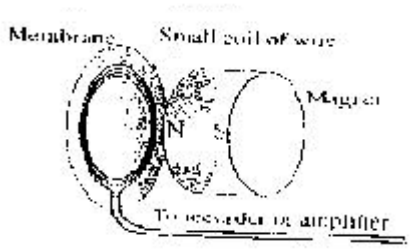
He experiences a problem in that he is unable to take measurable readings as the galvanometer needle only deflects slightly.

5.1	Is the magnetic field (flux) increasing or decreasing as he moves the magnet towards the coil? Explain your answer.	(3)
5.2	Mention two ways which Mpho can employ to increase the strength of current so as to take measurable readings.	(4)
5.3	State Lenz's Law used to determine the direction of the induced current.	(3)
5.4	In which direction is the N-pole of the magnetic field produced by an induced current pointing (left or right)?	(1)
5.5	Is the current flowing in the coil in a clockwise or anticlockwise direction?	(1)
		[12]

QUESTION 6

A microphone works on the principle of electromagnetic induction. A diagram showing the structure of the simple microphone is shown in the diagram below.

Diagram of a microphone that works by induction



6.1 Define electromagnetic induction. (3)
6.2 Use the diagram above to explain how a microphone works. (4)
6.3 What energy transformations take place when the microphone is transmitting sound? (2)
[9]

QUESTION 7

7.1 State Faraday's Law of electromagnetic induction in words. (3)
7.2 Mention two factors that influence the magnitude of magnetic flux. (2)

A coil of 240 turns has a radius of 2,5cm. The magnetic field strength increases from 0,5T to 2T in 0,5s when the magnet is moved inside the coil. Calculate:

7.3 the area enclosed by the surface of the coil. (3)
7.4 the rate of change in magnetic flux. (3)
7.5 the emf induced in the coil. (3)
7.6 the current induced if the coil has a resistance of 36Ω. (3)
[17]

QUESTION 8

Kholofelo uses a transformer to change 240V into 12V to operate a ticker timer. Transformers operate on the principle of mutual induction.

8.1 What is meant by 'mutual induction'? (3)
8.2 Calculate the number of turns in the secondary coil if the primary coil has 100 turns. (3)
8.3 What will the current in the primary coil be, if a current of 2A flows through the secondary coil? (3)
8.4 Mention three ways of improving the efficiency of a transformer. (3)
[12]

DATA SHEET

FORMULAE

ELECTROMAGNETISM

$\varepsilon = -N\frac{\Delta\varphi}{\Delta t}$	$\varphi = BA$
$\frac{Vs}{Vp} = \frac{Ns}{Np}$	$F = qvB$

CURRENT ELECTRICITY

$I = \frac{Q}{\Delta t}$	$R = \frac{V}{I}$

AREA

Rectangle: A = ℓ x b	**Circle: A =Πr^2**

PHYSICAL SCIENCES MEMORANDUM

ELECTROMAGNETIC INDUCTION

GRADE 11 **MARKS: 85**

SECTION A

QUESTION 1

1.1	Electromagnetic induction	(1)
1.2	Changing magnetic field (flux)	(1)
1.3	Weber	(1)
1.4	Magnetic field strength	(1)
1.5	Transformer	(1)
		[5]

QUESTION 2

2.1	False. ... a changing magnetic field (flux)	(2)
2.2	True	(2)
2.3	False. The magnitude of the magnetic flux is at **maximum** when the surface of the coil is **perpendicular** to the magnetic field. **Or** The magnitude of the magnetic flux is at **zero** when the surface of the coil is **parallel** to the magnetic field.	(2)
2.4	False. A **step-down** transformer increases the induced current and decreases the voltage. **Or** A **step-up** transformer decreases the induced current and increases the voltage.	(2)
2.5	False. The ratio of the voltages across the coils in a transformer is directly proportional to the number of turns in each coil and inversely proportional to the ratio of the currents.	(2)
		[10]

QUESTION 3

3.1	C	(2)
3.2	A	(2)
3.3	D	(2)
3.4	C	(2)
3.5	D	(2)
		[10]

QUESTION 4

4.1 What is the effect of moving a magnet relative to a coil? (2)

4.2 A moving or changing magnetic field (flux) induces an emf that produces an induced current. (2)

4.3.1 independent- magnet/magnetic field (flux). (1)

4.3.2 dependent – current. (1)

4.4.1 the needle deflects. (1)

4.4.2 the needle remains stationary. (1)

4.5 A moving or changing magnetic field (flux) induces an emf that produces an induced current. (2)

[10]

QUESTION 5

5.1 Increasing. More magnetic field (flux) lines cut the coil as the magnet moves into the coil. (3)

5.2 increase the speed of movement of the magnet;
Increase the strength of the magnet;
Increase the number of turns in the coil. **(Any two)** (4)

5.3 A current induced by an emf moves in a direction so that its magnetic field opposes that of a changing magnetic field (flux). (3)

5.4 Right. (1)

5.5 Clockwise. (1)

[12]

QUESTION 6

6.1 A process in which an emf is induced by a changing magnetic field to set up an induced current. (3)

6.2 The coil moves when sound waves strike the membrane. The motion of the coil changes the magnetic field (flux) around the magnet. The changing magnetic field induces (produces) an emf in the coil. The induced emf sets up an electric current in the coil. (4)

6.3 Kinetic energy is transformed into electrical energy. (2)

[9]

QUESTION 7

7.1 The magnitude of the induced emf is directly proportional to the rate of change of the magnetic flux linking with the conductor. (3)

7.2 Magnetic field strength; and the area enclosed by the coil. (2)

$N = 240$; $r = 2,5cm = 0.025m$; $B_i = 0,5T$; $B_f = 2,0T$; $\Delta t = 0,5s$

7.3 $A = \Pi r^2 = \Pi(0,025)^2 = 1,96x10^{-3}m^2$ (3)

7.4 $\frac{\Delta \varphi}{\Delta t} = \frac{(B_f - B_i)}{\Delta t} A = \frac{(2,0 - 0,5)(1,96x10^{-3})}{0,5} = 5,88x10^{-3}T.m^2.s^{-1}$ (3)

7.5 $\varepsilon = -N \frac{\Delta \varphi}{\Delta t} = -(240)(5,88x10^{-3}) = -1,41 = 1,41V$ (3)

7.6 $R = \frac{\varepsilon}{I}$

$36 = \frac{1,41}{I}$

$I = 0,03V$ (3)

[17]

QUESTION 8

8.1 Mutual induction is a process whereby an emf in the secondary circuit (nearby coil) is induced by an alternating current that sets up a changing magnetic flux (field) in the primary circuit to produce an induced current (ac or dc). (3)

8.2 Vp = 240V; Vs = 12V; Np = 100; Ns = ?

$\frac{Ns}{Np} = \frac{Vs}{Vp}$

$\frac{Ns}{100} = \frac{12}{240}$

Ns = 5 turns (3)

8.3 VpIp = VsIs

240xIp = 12 x 2

Ip = 0,1A (3)

8.4 Laminating the soft iron core;
Wrapping the coils on top of each other;
Filling the transformer with viscous oil. (3)

[12]

APPENDIX K

Approval letter from Human Research Ethics Committee (HREC)

Wits School of Education

27 St Andrews Road, Parktown, Johannesburg, 2193 • Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3007 • Fax: +27 11 717-3009 • E-mail: enquiries@educ.wits.ac.za •
Website: www.wits.ac.za

STUDENT NUMBER: 0616624H
Protocol: 2009ECE47
29 September 2009

Mr. Gideon Nkosi
27 Mtshali Street
CRYSTAL PARK
1515

Dear Mr. Nkosi

Application for Ethics Clearance: Master of Science

I have a pleasure in advising you that the Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate has agreed to approve your application for ethics clearance submitted for your proposal entitled:

A self-study on learning and teaching electromagnetism in Grade 11.

Recommendation:

Ethics clearance is granted

Yours sincerely

Matsie Mabeta
Wits School of Education

APPENDIX L

Approval letter from Gauteng Department of Education

UMnyango WezeMfundo
Department of Education

Lefapha la Thuto
Departement van Onderwys

Enquiries: Nomvula Ubisi (011)3550488

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

Permission has been granted to proceed with the above study subject to the conditions listed below being met, and may be withdrawn should any of these conditions be flouted:

1. ***The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.***

2. ***The District/Head Office Senior Manager/s must be approached separately, and in writing, for permission to involve District/Head Office Officials in the project.***
3. ***A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher/s have been granted permission from the Gauteng Department of Education to conduct the research study.***
4. ***A letter / document that outlines the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned, respectively.***
5. ***The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, and chairpersons of the SGBs, teachers and learners involved. Persons who offer their co-operation will not receive additional remuneration from the Department while those that opt not to participate will not be penalised in any way.***
6. ***Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal (if at a school) and/or Director (if at a district/head office) must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.***
7. ***Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year.***
8. ***Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.***
9. ***It is the researcher's responsibility to obtain written parental consent of all learners that are expected to participate in the study.***
10. ***The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources.***
11. ***The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations.***
12. ***On completion of the study the researcher must supply the Director: Knowledge Management & Research with one Hard Cover bound and one Ring bound copy of the final, approved research report. The researcher would also provide the said manager with an electronic copy of the research abstract/summary and/or annotation.***
13. ***The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned.***
14. ***Should the researcher have been involved with research at a school and/or a district/head office level, the Director concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.***

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

Pp Nomvula Ubisi
CHIEF DIRECTOR: INFORMATION & KNOWLEDGE MANAGEMENT

Office of the Chief Director: Information and Knowledge Management
Room 501, 111 Commissioner Street, Johannesburg, 2000 P.O.Box 7710, Johannesburg, 2000
Tel: (011) 355-0809 Fax: (011) 355-0734

Letter to the Principal

Dear Principal

RE: APPLICATION FOR PERMISSION TO USE LEARNERS AND SCHOOL

I hereby apply for permission to use the learners and facilities of your school to conduct a research project based on science education.

I am currently registered with the University of the Witwatersrand where I am enrolled for a Masters in Science Education. As part of my studies, I am expected to conduct a research project which requires that I be attached to a school in order to complete my course work.

The research is on *Electromagnetism*, a topic that is taught in grade 11 in the new curriculum. The abstract nature of the topic as well as the difficulty associated with learning and teaching it has prompted me to embark on a self-study on how I can better learn to teach the topic effectively.

The study requires that I conduct a series of six lessons of which each will last a period of one hour. The lessons require that I use a science laboratory to afford the learners the opportunity to learn from practical experiences. Piloting these lessons to your learners will benefit them as I intend using new approaches to teaching the topic. These lessons will be conducted during school hours in the third term of the school calendar as they form part of the curriculum.

All six lessons will be audio-taped and video-recorded so that I can collect as much data as possible from them. The tapes and transcripts of these lessons will be used only for research purposes. The school will be allowed to keep these tapes for educational purposes provided permission is obtained from the parents of the learners. Otherwise these tapes and transcripts will be destroyed after the study is completed.

Learners who do not wish to take part in the study and those whose parents do not want them to be part of the study will be excluded from these sessions. An alternative arrangement will be sought from these learners and their parents to ensure that I teach them this topic at their convenient time.

Learners who wish to be part of the study but want their identity to be kept confidential will be placed at strategic positions in class so that they are not captured by the video. Their names will be erased both in the video and the audio tapes. Pseudonyms will be used for both the school and the learners unless otherwise permission is granted by the school, parents and learners.

A letter requesting permission to conduct research at your school was sent to the Gauteng Department of Education Offices in Braamfontein. The response will be forwarded to the school as soon as permission to conduct research is granted.

Attached is a letter and consent form asking permission from parents to allow their children to take part in this exciting educational endeavour.

Thanking you in advance.

Yours sincerely

Gideon Nkosi

_____

APPENDIX N

Letter to the Parents and Consent Form

Dear Parent(s)

I hereby ask for permission to allow your child to take part in a research project that I will be conducting at the secondary school during the third term of the school calendar.

I am currently registered with the University of the Witwatersrand where I am enrolled for a Masters in Science Education. As part of my studies, I am expected to pilot six lessons to Grade 11 Physical Sciences learners using materials that I have developed on the topic on *Electromagnetism*. The abstract nature of the topic and the challenges associated with its learning and teaching has prompted me to embark on this self-study to learn to teach the topic effectively.

All six lessons will be audio-taped and video-recorded so that I can collect as much data as possible from them. The tapes and transcripts of these lessons will be used only for research purposes. The school will be allowed to keep these tapes for educational purposes provided permission is granted by the parents of all learners. Otherwise these tapes and transcripts will be destroyed after the study is completed.

Learners who do not wish to take part in the study and those whose parents do not want them to be part of the study will be excluded from these sessions. However, alternative arrangements will be sought from these learners and their parents to ensure that I teach them this topic at their convenient time.

Learners who wish to be part of the study but want their identity to be kept confidential will be placed at strategic positions in the classroom so that they are not captured by the video. Their names will be erased both in the video and audio tapes. Learners who later wish to withdraw from the sessions will be allowed to do so. Pseudonyms will be used for both the school and the learners unless both parties wish otherwise.

Allowing your child to be part of the study will benefit him/her in that I intend using new approaches to teaching the topic. The lessons will be conducted in the school science laboratory to ensure that learners are afforded maximum opportunities to learn from practical experiences. These lessons will be conducted during school hours as this topic forms part of the Grade 11 new curriculum.

Attached is a consent form to be completed by the parents responding whether or not they would like their children to be part of this exciting educational experience.

Thanking you in advance.

Yours sincerely
Gideon Nkosi

Signature of the Teacher: _____

School Stamp

RETURN SLIP

CONSENT FORM

I, _____ parent/guardian of the learner _____ in grade 11 hereby **grant/do not grant** permission for my child to be part of the Physical Sciences research project that will be conducted at school during the third term of the school calendar. I understand that his/her participation is voluntary and that he/she may withdraw at anytime if he/she no longer wishes to be part of the study.

Signature of Parent: _____ Date: _____