Exploring teachers' interpretation of the curriculum on Faraday's law in relation to their PCK

A dissertation submitted by

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DEDICATION

I dedicate this dissertation to Mariska du Preez, who passed on the 4th of August 2021. This dissertation would not have been possible without you.

Requiescat In Pace

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To whom it may concern

This letter serves to inform you that I have done language editing, proofreading, and reference formatting on the master's thesis

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ABSTRACT

The aim of this study was to understand how teachers' Pedagogical Content Knowledge (PCK) recorded through non-observational means is related to their interpretation of the South African curriculum in Faraday's law. Curriculum enactment by the teachers during the teaching of their lessons was used as an indication of their curriculum interpretation. Four Grade 11 teachers from schools in the Tshwane municipality were chosen through purposive and convenience sampling as participants for this study. The data reflecting teachers' PCK about Faraday's law (reported PCK) was captured with the use of Content Representations (CoRes) and pre-interviews. From the assumption that teachers' interpretation of the curriculum is reflected in their lesson presentations, data collected from lesson observations and post-interviews was compared to the information contained in the curriculum to determine how teachers' presentation of lessons on Faraday's law aligned to the curriculum, or deviated from it. The Topic-Specific Pedagogical Content Knowledge (TSPCK) model was used as the conceptual framework of this study that guided the characterisation of the teachers' reported PCK about Faraday's law in terms of five components, namely: *curricular saliency*, *what is difficult to teach*, *learners' prior knowledge and misconceptions*, *representations*, and *conceptual teaching strategies*. Teachers were assigned a competency level based on their knowledge within each of these components using a rubric. The teachers' interpretations of the curriculum were then compared to their reported PCK. The analysis specifically looked at whether teachers presented their lessons in a similar way to the curriculum or adapted or extended it for promoting conceptual understanding, and whether this related to their level of competence in a particular component of PCK.

The results of this study showed that teachers' interpretation of the curriculum, in terms of what is stated in it and whether it requires extensions in order to aid conceptual understanding, was predominantly attributed to their level of competence within a particular component of PCK. Examples included adapting the sequencing of concepts in the curriculum and extending it by using representations that are not alluded to in it. However, there were also a few instances where teachers' interpretation of the curriculum did not align with their level of reported PCK about Faraday's law. Based on these findings, recommendations were made for the curriculum to be expanded to include information that would further inform teachers' PCK of Faraday's law as the teachers of this study mostly interpreted the curriculum at face value. Pre-service teacher training should also place emphasis on developing teachers' ability to interpret and analyse the curriculum in terms of the components of TSPCK so that they are able to recognise shortcomings which require adaptions or extensions in order to design conceptually effective lessons.

Key Words

Topic-Specific Pedagogical Content Knowledge; Reported PCK; Curriculum interpretation; Faraday's law; Content Representations

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LIST OF ABBREVIATIONS

CAPS	Curriculum and Assessment Policy Statement
FET	Further Education and Training
GDE	Gauteng Department of Education
PCK	Pedagogical Content Knowledge
SCK	Specialised Content Knowledge
TSPCK	Topic-Specific Pedagogical Content Knowledge
MRTEQ	Minimum Requirements for Teacher Education Qualifications
TIMSS	The International Mathematics and Science Study
DoBE	Department of Basic Education
emf	Electromotive force
RHR	Right Hand Rule

CHAPTER ONE: INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 INTRODUCTION

This study focused on exploring teachers' interpretation of the South African Physical Sciences curriculum on Faraday's law in relation to their reported Pedagogical Content Knowledge (PCK). This study holds that teachers' enactment of the curriculum during lesson presentations is an indication of their interpretation of the curriculum. The motivation for this study came from the importance of Faraday's law as a topic which connects a number of other topics studied by learners from Grade 10 to 12 in the Physical Sciences curriculum in South Africa. Research has indicated that learners find Faraday's law and the topic of electromagnetic induction difficult (Román, 2012; Zuza, Almudí, Leniz, & Guisasola, 2014). These challenges may arise from the need for learners to integrate their knowledge of other concepts such as magnetic field, magnetic flux, electric field, electromotive force, and current (Chabay & Sherwood, 2006; Jelicic, Planinic, & Planinsic, 2017). The difficulty of this topic naturally calls for teachers to have the ability to transform its content into forms that are understandable to learners through effective instruction. Such an ability is integral to the teaching profession but especially important to the subject of Physical Sciences where many of the topics are seen as abstract and difficult.

1.2 BACKGROUND TO THE STUDY

According to the Minimum Requirements for Teacher Education Qualifications (MRTEQ) document of the Republic of South Africa (Department of Higher Education and Training [DHET], 2015, p. 9), teaching is described as follows:

> Teaching is a complex activity that is premised upon the acquisition, integration and application of different types of knowledge practices or learning. A purely skills based approach, which relies almost exclusively on evidence of demonstrable outcomes as measures of success, without paying attention to how knowledge should underpin these skills for them to impact effectively on learning, will produce technicians who may be able to replicate performance in similar contexts, but who are severely challenged when the context changes.

One can easily be forgiven for thinking that both knowledge of content and knowledge of teaching have always been jointly regarded as necessary for teaching. The recognition in the quote above by the MRTEQ document that teacher competency lies neither in teacher knowledge nor skill alone is a recent stance which culminates from decades of debate regarding teacher knowledge.

This debate was brought to the forefront of educational research by the educational psychologist Lee Shulman. Shulman (1986) was acutely aware of the narrow view held by research and policy in the 1980s of what teaching was and the knowledge necessary for teachers to possess which allowed them to be effective teachers. He noted the sharp change in teacher standards which saw a shift in testing almost exclusively teacher subject matter knowledge, to that of testing for pedagogical knowledge and skill. Shulman referred to the absence of teacher subject matter knowledge in research and policy as the "missing paradigm" (1986, p. 6). This one-sided view of teacher knowledge has permeated teacher education programmes resulting in training focused either on content knowledge or pedagogical knowledge (Mishra & Koehler, 2006). Shulman knew, however, that content and pedagogical knowledge were inextricably linked. He began to conceptualise this relationship as a knowledge base of teachers that was the amalgamation of content and pedagogical knowledge, which he termed pedagogical content knowledge (PCK). PCK is believed to be the knowledge that allows teachers to transform what the teacher knows (content knowledge) into what the learners should know through understandable ideas that lead to effective instruction (Shulman, 1986). The significance of such a knowledge base and the extent to which it is developed by teachers is especially important in the South African context and within the subject of Physical Sciences. It is well known that science is a difficult subject for learners worldwide (Thomas, 2013). South Africa is no exception as evidenced in the National Senior Certificate diagnostic reports which show a decline in learners' performance in the subject (Department of Basic Education [DoBE], 2019b; 2020).

1.3 CONTEXT: SCIENCE TEACHING IN SOUTH AFRICA

The DoBE regards Physical Sciences and Mathematics as gateway subjects that have the possibility to open up a number of study choices to learners after high school

(2019a). The ability for these subjects to “open doors” is regularly quoted by stakeholders in education, however, this is seldom the reality of the majority of the learners in South African public schools. South Africa faces a crisis in terms of the number and quality of Physical Sciences learners that it is producing. The year 2019 saw a matric pass rate of 75% in Physical Sciences, a seemingly large improvement from the 58,6% in 2015 (Matangria, 2020). However these statistics provide little hope when viewed in context. The total number of candidates who sat to write the Physical Sciences exams in 2019 was the lowest recorded in the previous five years with 8000 fewer learners entered compared to 2018 (Head, 2020). The pass rate also does not reflect the reality that many Physical Sciences learners’ scientific and mathematical literacy is inadequate as they are required to obtain at least 30% to pass the subject. Learners are unprepared and unable to compete in a globalised world in which the Fourth Industrial Revolution strongly demands knowledge and understanding of scientific concepts (Department of Science and Technology, 2018). This is evident from the Trends in International Mathematics and Science Study (TIMSS) used to benchmark the performance of learners in Mathematics and Science from an array of countries. The 2019 TIMSS found that Grade nine South African learners performed the poorest in science, placing them last out of 39 countries (Mullis, Martin, Foy, Kelly, & Fishbein, 2020). In South Africa in particular, the poor performance of learners in Physical Sciences has been linked to poorly trained science teachers that lack the requisite knowledge to teach (Centre for Development Enterprise, 2011). Factors such as unqualified and under-qualified teachers and outdated teaching practices have been identified as factors that have contributed towards this poor performance (Mji & Makgato, 2006). Kind (2009) believed that the lack of content knowledge and understanding of scientific principles by science teachers has the greatest negative impact on learner performance. According to Reddy et al. (2012), the TIMSS of 2011 indicated that only 53% of science learners in South Africa are taught by teachers that hold a degree. This is in contrast to the 90% of science learners internationally of the schools that participated in TIMMS 2011 who are taught by teachers with degrees (Reddy et al., 2012). South African science teachers who do not hold degrees will thus have less content knowledge than their international counterparts, impacting the extent to which they are able to teach the subject effectively.

In the report on the quantity and quality of South African teachers published by the Centre for Development Enterprise (2011), it was noted that South African teachers' subject matter knowledge falls well short of international norms and standards. A number of studies have found that a teacher's subject matter knowledge has a direct influence on their PCK and is thus considered a pre-requisite for PCK (Hartati, Permanasari, Sopandi, & Mudzakir, 2019; Neumann, Kind, & Harms, 2019; Ozden, 2008).

1.4 PROBLEM STATEMENT

> Instead of promoting teachers as professionals, the government has unfortunately relied more on traditional approaches which rely heavily on 'experts' who design a curriculum that teachers are expected to implement. (Msibi & Mchunu, 2013, pp. 20-21)

The quote above refers to the South African government's perception of teachers as technicians rather than professionals. This view of teachers can be traced back to the Apartheid era during which teacher training sought to create docile and compliant teachers who would implement a curriculum that was not to be questioned or subverted (Kimathi & Rusznyak, 2018). Change was brought in 1994 as South Africa entered into its democratic era which was accompanied by a complete overhaul of the education system. Educational reform looking to address the deeply rooted inequalities created by the Apartheid education system presented itself in the form of the development and implementation of four different curricula in the span of 15 years since 1997. Teachers play an integral part in the process of reformation but their role in curriculum development and implementation can often be overlooked or purposefully undermined. This is evident in South Africa which has seen the slow erosion of the status of teachers from professionals to that of lay technicians. Msibi and Mchunu (2013) were of the view that in the government's efforts to reform the South African education system from that of the Apartheid era to post 1994, it set its focus on reforming the curriculum while losing sight of its teachers and their poor levels of competency. Curriculum 2005 which sought to address the inequalities of the Apartheid era required that teachers learn new teaching methods but overlooked their capabilities. The following curriculum named The Revised National Curriculum Statement (RNCS) introduced in 2004 had even higher expectations of teachers which once again did not match their capabilities. The RNCS placed emphasis on teacher training and curriculum implementation, viewing teachers as designers of their own learning programmes for their learners and not simply as implementers of a curriculum plan (Green, 2007). This is in line with the Norms and Standards for Educators designed eight years prior to the NCS's implementation. The Norms and Standards for Educators (DoBE, 2000, p. 13) stated one of the seven roles of teachers as that of an interpreter of the curriculum as follows:

> [An] educator will understand and interpret provided learning programmes, design original learning programmes, identify the requirements for a specific context of learning and select and prepare suitable textual and visual resources for learning. The educator will also select, sequence and pace the learning in a manner sensitive to the differing needs of the subject/learning area and learners.

Mbatha (2016) stressed this role, noting that any curriculum is at the mercy of a teacher who will interpret it in the class. However, it was not long until South Africa was again faced with implementing a new curriculum in 2012 named the Curriculum and Assessment Policy Statement (CAPS). CAPS has been described by researchers as being "teacher-proof" (Msibi & Mchunu, 2013, p. 19). Teachers' inputs, creativity, and autonomy in interpreting and implementing have been largely limited, with their role being reduced to implementers of a curriculum that has been designed by experts (Msibi & Mchunu, 2013). Msibi and Mchunu (2013) are of the view that in order for teachers to cope with the changes in the curriculum and be able to implement it, the lack of teacher professionalism needs to be addressed. Their conception of teacher professionalism is associated with, among other things, the ability to implement a curriculum which requires a specialised knowledge base unique to the teaching profession.

The perceived role of teachers as lay-technicians who merely transfer knowledge as opposed to professionals with specialised knowledge is often linked to society's view as to the professional status of the occupation. This was well understood by Shulman (1987) whose efforts to elevate teaching to that of a respected and professional occupation led him to describing knowledge bases of teaching that could be used as standards for the evaluation of the teaching profession. Of these knowledge bases, PCK is the most significant as it acknowledges the relationship between both content and pedagogical knowledge. The Norms and Standards for Educators (DoBE, 2000,

p. 17) which continues to govern the roles of teachers recognises the importance of PCK in a teacher's ability to interpret a curriculum, stating that teachers need to understand "the learning area to be taught, including appropriate content knowledge, pedagogic content knowledge, and how to integrate this knowledge with other subjects".

What is not yet well understood is how a teacher's reported PCK is related to their interpretation of the expectations of the curriculum in order to plan and execute effective lessons. The successful implementation of a curriculum requires that teachers have the ability to interpret a curriculum and its expectations into teaching that will fulfil these expectations (Kabombwe, 2019). Curriculum interpretation includes the capacity to identify whether or not there are shortcomings in the curriculum that require extensions or adaptions of it. Curriculum interpretation is central to the current study which sought to understand teachers' enactment of the curriculum on Faraday's law and how it is related to their reported PCK. Faraday's law is part of the topic of electromagnetism in the South African Physical Sciences curriculum.

1.5 RATIONALE OF THE STUDY

Researchers have reported that the topic of electromagnetism is regarded as difficult for learners (Constantinou, Papaevripidou, Lividjis, Scholinaki, & Hadjilouca, 2010; Sağlam & Millar, 2006) and is seen as particularly problematic for Grade 12 learners in SA. A look at the performance of a random sample of learners during the National Senior Certificate exams over the last four years for the question covering Electrodynamics (recorded in the DBE's Diagnostic Reports), shows an overall poor performance in the topic with learners achieving an average below 50 %. This is much lower than that of the questions relating to difficult topics such as Newton's Laws and Vertical Projectile Motion whose averages were close to 60% (DoBE, 2015; 2016; 2017). The 2015 Diagnostic Report suggested that this poor performance may stem from learners having difficulties in interpreting Faraday's law which is an integral part of electromagnetism. Faraday's law includes new concepts such as magnetic flux which can prove challenging for learners to grasp. The role of effective teaching in leading learners to attaining sound conceptual understanding of Faraday's law cannot be overstated. The process of teaching usually begins with the teacher first determining what learners are expected to know and be able to do regarding a particular topic. These expectations are stated in the curriculum (CAPS document) as set by the DBE. Although the curriculum prescribes the knowledge and skills that learners are expected to have, as well as providing guidance to teachers as to what practical activities should be performed to aid learner understanding, it in no way is a definitive guide as to how to teach the content. This requires teachers to interpret the expectations of the curriculum using their specialised knowledge of, among others, how to represent concepts, the prior knowledge that learners have, and the ordering of topics and concepts for conceptual understanding. This specialised knowledge is included in PCK.

The word 'curriculum' has a range of meanings which emanate from the transformation and changes that occur as it is being implemented at different levels (Carl, 2012). It usually refers to the planned curriculum that presents itself in the form of a policy document set by departments of education (Murphy & Pushor, 2010). This document requires teachers to interpret and translate the curriculum into a plan of instruction that includes learning experiences that are appropriate for their learners. What is actually taught in the classroom and the skills and knowledge displayed by the teacher in the class comprise the operational or enacted curriculum. Meaningful implementation of the planned curriculum only occurs through the interpretation of the teacher (Ross, 2017). In a PCK study conducted by Coetzee (2018), it was found that pre-service Physical Sciences teachers did not recognise the importance of magnetic flux in the topic of Faraday's law. The curriculum introduces this concept under the heading of Faraday's law and not explicitly as a sub-topic. Only after they were encouraged to think about the importance of magnetic flux, did they realise that it can be explained before introducing Faraday's law. This thus leads to questions such as: How do teachers interpret the curriculum on Faraday's law, and how is this interpretation influenced by the PCK that they possess in that particular topic?

1.6 AIM OF THE STUDY

This study sought to explore teachers' interpretation of the curriculum on Faraday's law in relation to their reported PCK. Curriculum enactment during the presentation of lessons was taken as an indication of the teachers' interpretation of the curriculum which was further corroborated by data collected from post-interviews. Teachers are required to apply their PCK during the interpretation of the curriculum in order to design lessons that lead to effective teaching. The aim of this study was to understand how teachers' interpretation of the curriculum in Faraday's law is related to their reported PCK. This study was guided by the following research questions.

1.7 RESEARCH QUESTIONS

Primary Research Question:

How can selected teachers' enactment of the curriculum on Faraday's law be understood in relation to their reported PCK?

Secondary Research Questions:

1. How can the curriculum on Faraday's law be characterised in terms of the topic-specific PCK components?
2. How can selected teachers' reported PCK about Faraday's law be characterised?
3. How do the teachers' presentation of lessons on Faraday's law align to the curriculum, or deviate from it?

1.8 CONCEPT CLARIFICATION

- **Pedagogical Content Knowledge**: This term refers to the amalgamation of content knowledge and pedagogical knowledge that allows a teacher to transform content into effective instruction.
- **Topic-Specific Pedagogical Content Knowledge**: This term refers to the PCK held by a teacher in a particular topic and is divided into five components: *curricular saliency*, *what is difficult to teach*, *learners' prior knowledge and misconceptions*, and *conceptual teaching strategies*.
- **Reported PCK**: The PCK captured outside of the classroom through non-observational data collection techniques which include verbal and written means using data collection tools such as CoRes and pre-interviews.

- **Curriculum interpretation**: The process during which a teacher unpacks the curriculum for the planning or delivery of lessons on a particular topic. Enactment of the curriculum during lesson presentations is an indication of curriculum interpretation.

1.9 SUMMARY

This chapter has presented a justification for the undertaking of this study and the research questions that have guided it. The importance of understanding teachers' interpretation of the curriculum in terms of their reported PCK within the South African context has been clearly delineated. Furthermore, an argument was presented for the reason behind the focus for studying teachers' interpretation of the curriculum specifically within Faraday's law in Physical Sciences.

The chapters that follow provide a review of the literature on the topic of Electromagnetism and Faraday's law as well as the conceptual framework of this study. The research paradigm and research methodology that guided this study are discussed, after which an analysis of the data collected is presented. Finally, with limitations of the study and recommendations for future research and practice conclude the study.

CHAPTER TWO: LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 INTRODUCTION

This chapter explores the literature on the topic of Electromagnetism and factors that may lead to it being considered a difficult concept for teaching and learning. The construct of PCK as a form of teacher knowledge is discussed with Mavhunga and Rollnick's (2013) Topic-Specific PCK (TSPCK) Model introduced as the conceptual framework of this study. In addition, the role of the teacher as a curriculum interpreter, and by extension, the influence that teachers have on ensuring effective teaching takes place is reviewed. Lastly, tools that were developed by researchers to capture and assess PCK and their employment in this study are discussed.

2.2 DIFFICULTIES IN UNDERSTANDING ELECTROMAGNETISM

Electromagnetic induction and Faraday's law have been shown by researchers to be poorly understood by learners (Coetzee, 2018; Guisasola, Almudí, & Zubimendi, 2004; Hekkenberg, Lemmer, & Dekkers, 2015; Sağlam & Millar, 2006; Zuza et al., 2014). Researchers have found that difficulties in understanding concepts related to these topics persist long after learners have been introduced to them with studies indicating that both the teaching and learning of Faraday's law are problematic (Zuza et al., 2014). In studying the PCK of pre-service Physical Sciences teachers in the topic of Electromagnetism, Coetzee (2018) found that pre-service teachers did not consider magnetic flux as an important idea in understanding the electromotive force described by Faraday's law. As a result, the pre-service teachers did not teach magnetic flux before introducing Faraday's law. Such sequencing could further contribute to the poor understanding learners have of Faraday's law.

Faraday's law is central to understanding the relationship between electricity and magnetism and thus electromagnetic induction. The law relies on the concept of magnetic flux which is a difficult concept for learners to grasp as it is new to learners and is often confused as being the magnetic field itself (Jelicic et al., 2017; Zuza et al., 2014), a simpler concept developed earlier on by learners. Difficulties in understanding the nature of magnetic flux and the failure by learners to realise the change in magnetic flux as a cause of electromagnetic induction has resulted in learners using Faraday’s law with insufficient understanding (Jelicic et al., 2017). This was also reported in research conducted by Maloney, O'Kuma, Hieggelke, and van Heuvelen (2001) which showed that learners failed to identify the dependence of electromotive force (emf) on the *rate of change* of factors such as magnetic flux or electric current. Further difficulties with the concept of magnetic flux were found in a study conducted by Albe, Venturini, and Lascours (2001). Their study found that pre-service science teachers were unable to correctly define magnetic flux, providing definitions that included only certain elements of the correct definition while the majority of Physical Science undergraduates were unable to define the concept or use its equation in simple problem situations. This poor understanding of magnetic flux by science students will impact the way in which the topic of Faraday’s law is taught by those who choose to become teachers. Electromagnetic induction and magnetic flux are also considered difficult among learners since these concepts cannot be seen directly and are not phenomena learners are aware of in their everyday lives as opposed to concepts in mechanics such as forces (Jelicic et al., 2017). The topic of Electromagnetism is introduced to learners for the first time in Grade 11. Because they have not dealt with magnetic flux before this topic, learners are unfamiliar with the concept and the accompanying language that is used to describe it. This must be kept in mind when teaching the topic of Faraday’s law since learners have no experience with many of the concepts that it involves. It is therefore pertinent for teachers to have knowledge of a variety of teaching strategies as well as representations to explain such a topic to learners.

Zuza et al. (2014) explained that traditionally, teaching of the underlying concepts in Electromagnetism (such as Faraday’s law and magnetic flux) are not done in a manner that allow for conceptual understanding. Rather, the majority of the time is spent teaching strategies that promote algorithms for the solving of exercises. Gaigher, Rogan, and Braun (2007) attribute this form of problem-solving of typical textbook questions in South African schools to conditions created by poorly trained teachers, teacher-centred classes and rote learning, stating that “in such conditions, physics problem-solving is likely to be reduced to algebraic solutions, with little, if any, emphasis on conceptual understanding." Research conducted by Bagno, Eylon, and Ganiel (2000) also found that learners tend to memorise mathematical relationships without developing a conceptual understanding. Faraday's law, which is used as a mathematical tool for the determination of the electromotive force, is susceptible to this kind of learning without conceptual understanding. A focus on solving problems involving Faraday's law may be ascribed to teachers' reliance on using learners' ability to solve mathematical problems as an indicator of understanding. Much emphasis is placed on the equation of Faraday's law and teaching learners how to substitute values with little time being devoted to teaching for conceptual understanding. Factors such as teachers' lack of content knowledge or poor understanding of these concepts must also be considered as contributing towards inadequate teaching strategies (Kind, 2009).

Much of the research conducted on electromagnetism has focused on the conceptions and understanding held specifically by university students, with limited research focused on the understanding held by high school students. Sağlam and Millar (2006) raised the concern for this lack of research since Electromagnetism is an important topic in the physics syllabus of many countries and is one that is considered difficult by many learners. This lack of research may be as a result of research focusing on the underlying concepts of electricity and magnetism and learner difficulties within these topics instead, as electromagnetic induction requires learners to integrate their knowledge about these two concepts (Jelicic et al., 2017; Zuza et al., 2014). Research conducted by Zuza et al. (2014) on comprehension difficulties among high school learners regarding electromagnetic induction corresponds with this notion. Some of the learning difficulties identified by Zuza et al. centre on the following: (a) learners are unable to distinguish between the empirical level (voltmeter and ammeter measurements) and the interpretive levels that use concepts such as electric and magnetic fields; (b) learners believe that a magnetic field produces an electromotive force; and (c) magnetic flux is understood by learners to be flowing from the magnetic field itself or is the magnetic field itself. Jelicic et al. (2017) believed that electromagnetic induction may be the most difficult topic in the domain of electricity and magnetism.

The research studies discussed above stressed the need for teachers to be aware of learners' prior knowledge and conceptions relating to certain topics and to know when revision of important concepts is necessary. This is particularly important in the South African context in which the topics of Electricity and Magnetism are introduced in Grade 10, whereas Electromagnetic Induction is discussed the following year in Grade 11. Sağlam and Millar (2006) suggested that teaching strategies be developed that help learners integrate the concepts of electromagnetic induction in a more coherent way. This is particularly important in electromagnetism, following that research has found it to be a difficult topic for learners to understand (Jelicic et al., 2017). Such strategies must assist learners in being able to visualise magnetic field patterns and their effects. Zuza et al. (2014) developed a teaching sequence for university students that would elicit and resolve difficulties held by students in Faraday's law. This teaching sequence was based on research that showed students needed guidance in understanding that Faraday's law focuses on two phenomena, the time variation of a magnetic field and the movement of a conductor through a magnetic field, or a combination of both. Both of these phenomena require students to have an understanding of magnetic flux. Such a teaching strategy at high school level could greatly assist in learners' understanding of Faraday's law where they are first introduced to it.

A starting point for the development of a teaching sequence for electromagnetic induction in high school may come from the research conducted by Román (2012) in which an historical approach is taken. Due to the abstractness of the topic of electromagnetism, Román (2012) advocated for a teaching sequence that incorporates relevant history perspectives related to developments in electromagnetism which also emphasise the influence of Faraday's law and its impact in today's society. The inclusion of historical elements in the teaching of science allows for thematical contents to be presented to learners with a more logical perspective. This is achieved by introducing students to landmark discoveries such as Oersted's compass that led to later developments. This provides a more realistic view of scientific knowledge production that avoids conceptual learning difficulties in particular topics.

The difficulties encountered by learners in the topic of Electromagnetism draw attention not only to the necessity for teachers to have the relevant content knowledge regarding this topic, but also the knowledge they should have in order to transform the content into that which learners can easily understand. The following section discusses a conception of this form of knowledge and its significance in promoting effective teaching.

2.3 PEDAGOGICAL CONTENT KNOWLEDGE

Teachers' knowledge of learner misconceptions has long been speculated to play a vital role in student learning and achievement. Sadler and Sonnert (2016) were of the opinion that learning entails both the unlearning of old ideas as much as the learning of new ones. For teachers to address the old ideas that often appear as misconceptions, they firstly need to be able to identify those held by their students. Sadler and Sonnert (2016) suggested that the ability of teachers to identify student misconceptions is a manifestation of PCK, a specialised form of professional knowledge conceived by Shulman (1986) that allows teachers to transform content into understandable instruction.

In an endeavour to improve the status of teaching and raise it to the level of a respected profession, Shulman (1987) sought to identify knowledge bases for teaching which were viewed as the aggregated knowledge, skill, and understanding of teachers. Shulman began to develop a theory to describe teacher knowledge and the domains or bases that constituted this knowledge. This would provide answers to the relationship that exists between content and pedagogical knowledge, how the domains that constitute this knowledge are represented in the minds of teachers, and how this knowledge acquisition can be enhanced. A growing belief by researchers in the 1980s in the United States was already beginning to form that there exists a knowledge base for teaching (Shulman, 1987). This was implicit in comments that high-quality teaching required sophisticated and professional knowledge (Ball, Thames, & Phelps, 2008). A knowledge base provided a means by which to quantify the knowledge held by teachers and thus could form the standards by which teacher performance could be measured. Identifying these knowledge bases would assist in elevating the professionalisation of teaching and inform teacher education. Reports at the time, however, failed to identify any characteristics of this knowledge base, leading Shulman (1986) to address this gap.

Seven typologies of professional knowledge were proposed by Shulman (1987) which underlie teacher understanding that promote learner comprehension. The first three categories of *Content knowledge*, *Curriculum knowledge* and *Pedagogical content knowledge* are content related, while the last four categories refer to *General pedagogical knowledge, Knowledge of learners and their characteristics, Knowledge of educational contexts*, and *Knowledge of educational purposes* (van Driel, Verloop, & de Vos, 1998). These seven categories were used to highlight the importance of content knowledge in the larger landscape of professional knowledge. However, Shulman did not seek to diminish the importance of pedagogical knowledge but rather to stress its interdependence with content knowledge, arguing that “mere content knowledge is likely to be as useless pedagogically as content-free skill” (Shulman, 1986, p. 8). Of particular importance, and also arguably the most important knowledge base of teachers, is the category of PCK. Shulman stated that:

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background represented by the students. (1987, p. 15)

Shulman described PCK as the amalgamation of subject matter knowledge and pedagogical knowledge resulting in subject matter *for teaching* and encompassed:

> the most useful forms of representation of [content], the most powerful analogies, illustrations, examples, explanations and demonstrations … the ways of representing and formulating subject matter that make it comprehensible to others. (1986, p. 9)

Lee and Luft (2008) were of the view that PCK is the knowledge that sets the scientist, who knows content, apart from the science teacher who knows content as well as how to teach it. This knowledge base contains knowledge of what topics are easy or difficult for learners, the conceptions and misconceptions that learners have of a particular topic as well as the background they bring with them to the learning of these topics. These can be considered as categories of knowledge that form PCK and are applied “synergistically to problems of teaching practice” (Abell, 2008, p. 1407).

Loughran, Berry, and Mulhall (2012) described PCK not just as the amalgamation of content and pedagogy, but as the interaction and shaping of each other. Thus, content that is taught is constructed in a manner that makes it comprehensible to learners by the way in which it has been organised, planned, analysed, and presented. PCK in science education has been of particular interest to researchers as it is a subject commonly regarded as difficult due to the number of abstract concepts that it deals with (Hlabane, 2016). It is for this reason that attention will be paid to the role of PCK in a science education, and in particular, PCK within the topic of Faraday's law.

2.4 TAXONOMIES OF PCK

Pedagogical Content Knowledge quickly became an accepted concept in the education community as a way of describing the professional knowledge of teachers after it was first introduced by Shulman in 1986. Veal and Makinster (1999), however, recognised that there was a lack of models that addressed the role of PCK in teacher professional development specifically within science education. This led them to designing a taxonomy that categorised the different types of PCK used in science education. Their General Taxonomy of PCK addressed the differences between and within various knowledge bases and the hierarchical process by which teachers obtain this knowledge. Veal and Makinster (1999) described the first level of PCK as *General PCK*. This level indicates the pedagogical knowledge such as concepts and strategies that are employed within the teaching of a specific discipline such as that of Mathematics, Science, or Art. Strategies employed in the teaching of science include discovery, inquiry, and project-based science and can be seen to represent a "general way of conceptualising science teaching" (Magnusson, Krajcik, & Borko, 1999, p. 5). Although such strategies could be employed in other subjects, their purpose, process, and content are unique to science, highlighting that pedagogy is discipline specific.

The second level is Domain-Specific PCK which distinguishes between domains within a discipline and therefore is more specified. Chemistry and Physics are seen as distinctive domains with their own characteristic PCK. Evidence of this particular form of PCK can be seen in the fact that although laboratory work may be conducted in both Chemistry and Physics, their purposes and tools are specific to their subject matter or domain.

The final level of PCK is Topic-Specific PCK (TSPCK). Veal and Makinster (1999) described this as the most novel level of PCK. According to Nezvalová (2011), a teacher who has knowledge on this level should be competent in the previous levels, having a wide repertoire of skills and abilities in general and domain-specific PCK. The basis for this level stems from the idea that topics or concepts within a domain have their own unique teaching styles and approaches to teaching them even if they are topics that appear in more than one domain. A Chemistry teacher's approach to gas behaviour would be from a different perspective to that of a Physics teacher. The existence of TSPCK is supported by a number of researchers (Geddis, Onslow, Benyon, & Oesch, 1993; Mavhunga & Rollnick, 2013; Veal & Makinster, 1999). Since TSPCK is associated with the teaching of particular topics such as Electromagnetism or Forces, this category of PCK is most relevant to this study and will form the foundation for the theoretical framework by which it is underpinned.

2.5 CONCEPTUAL FRAMEWORK

It was evident to Loughran, Mulhall, and Berry (2004) that a gap existed in research as to examples of TSPCK which could be used to illuminate important aspects of teachers' professional knowledge. The need for such examples of PCK on a particular topic in science stems from its ability to be analysed and dissected so that teacher knowledge can be articulated. These articulations and descriptions could serve as a blueprint for teaching by acting as a guide on the knowledge deemed necessary for pre-service teachers to attain during their training that would lead to them becoming effective teachers. This idea is supported by Mavhunga and Rollnick (2013) who explained that teachers should not only learn how to teach (obtain pedagogical knowledge) but also how to teach specific topics such as Electricity or Stoichiometry. Although the idea of PCK being topic specific was generally accepted among researchers, Mavhunga and Rollnick (2013) looked closer at the relationship between TSPCK and the transformation of content within a particular topic.

Shulman (1987, p. 16) argued that: "comprehended ideas must be transformed in some manner if they are to be taught". Geddis et al. (1993) elaborated on this, further pointing out that teachers need to develop the awareness that teaching requires the transformation of content (topic) knowledge, asserting that once this awareness is in place, the need for articulating the knowledge necessary for this transformation becomes important. Geddis et al. (1993 cited in Hume, Cooper, and Borowski, 2019,

p. 132) referred to this knowledge as a “multitude of particular things” that enhances the teachability of a specific content area. These ‘things’ were identified as: (i) *learners’ prior knowledge and misconceptions*; (ii) *curricular saliency*; (iii) *what is difficult to teach*; (iv) *representations*; and (v) *conceptual teaching strategies*.

These arguments have been accepted as evidence for the topic-specific nature of PCK and laid the foundation for the TSPCK model (Figure 2.1) developed by Mavhunga and Rollnick (2013). This model distinguishes between PCK and TSPCK. Drawing from previous research, Rollnick, Bennett, Rhemtula, Dharsey, and Ndlovu (2008) identified four fundamental domains of teacher knowledge which teachers draw from to inform their general PCK. These domains seen in Figure 2.1 are: *knowledge of context*; *knowledge of students*; *subject matter (content) knowledge*; and *pedagogical knowledge*. These domains are seen as forming a generic type of PCK at discipline level and are believed to be influenced by teachers’ beliefs toward the teaching of science (Mavhunga & Rollnick, 2013). The domains of *knowledge of students* and *pedagogical knowledge* are acknowledged as having a possible influence on TSPCK due to their similarity with two of its domains, *student’s prior knowledge*, and *conceptual teaching strategies* (Mavhunga & Rollnick, 2013).

TSPCK is differentiated from discipline PCK by the transformation of content knowledge through five content-specific components (Mavhunga & Rollnick, 2013). Mavhunga and Rollnick (2013) contended that when a particular element of content knowledge (K) in a topic is reasoned through these five Topic-Specific components, understanding is generated for teaching that particular topic (K).

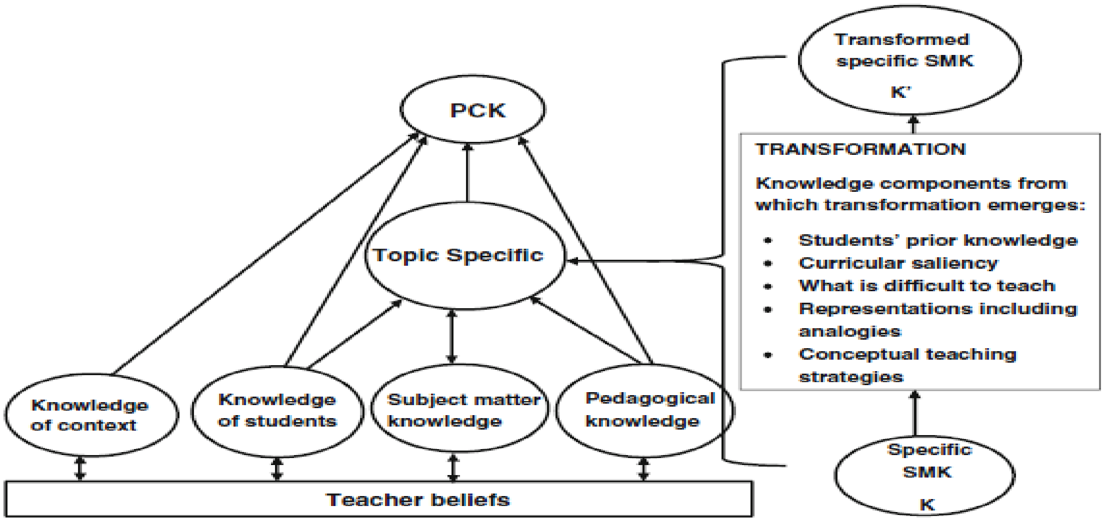


Figure 2.1: A model for Topic-Specific PCK (Mavhunga & Rollnick, 2013)

This transformation can be seen on the right-hand side of Figure 2.1. These five knowledge components are the "multitude of particular things" that were identified by Geddis et al. (1993, p. 676).

Similar components were identified by Ball et al. (2008) in Mathematics education which they refer to as Specialised Content Knowledge or SCK. The construct of SCK indicates the types of knowledge through which content knowledge should be filtered and transformed for teaching. SCK includes knowledge of learner prior conceptions, what is difficult to teach or understand, and strategies for teaching. Mavhunga and Rollnick (2013) drew attention to the fact that the quality of a teacher's TSPCK is found not only in their conceptual understanding of the five components, but also in their ability to identify the interactions between the various components.

2.6 COMPONENTS OF TOPIC-SPECIFIC PCK

A discussion of the five components of TSPCK is provided, clarifying the knowledge considered to be contained in each component. The order in which the components are discussed differs from that of the TSPCK model. As this study focuses on curriculum interpretation, the component of *curricular saliency* is discussed first. This component provides an overview of the curriculum in terms of a teachers' understanding of important ideas of a particular topic in the curriculum, the sequencing of these ideas, and their interrelatedness.

2.6.1 Curricular Saliency

Curricular saliency encompasses different aspects of knowledge relating to a topic which includes: (i) the structure of a topic and the key ideas constituting it; (ii) the relative position of the topic within the broader curriculum; and (iii) knowledge of how to sequence key ideas for their effective comprehension (Rollnick et al., 2008).

This component highlights teachers' ability to discern important concepts that learners need to understand as well as determine the depth of content (Shing, Saat, & Loke, 2015).

2.6.2 What is Difficult to Teach?

This component comprises teacher knowledge regarding gate-keeping concepts in a topic that may be difficult to teach or understood by learners. This requires teachers to know why certain concepts are difficult to teach or for learners to understand, and be conscious of these reasons when teaching them (Grossman, 1990).

2.6.3 Learners' Prior Knowledge and Misconceptions

Khourey-Bowers and Fenk (2009, pp. 437-438) asserted that knowledge of students' difficulties and effective teaching strategies are just as crucial as content knowledge in ensuring quality teaching, emphasising that:

> Teachers with broad and deep … subject specific knowledge, awareness of common alternative conceptions and … scientific models can provide rich learning opportunities for their students.

Sadler and Sonnert (2016) were of the opinion that learning entails both the unlearning of old ideas as much as the learning of new ones. For teachers to address the old ideas that often appear as misconceptions, they firstly need to be able to identify those held by their students. Sadler and Sonnert (2016) suggested that the ability of teachers to identify student misconceptions is a manifestation of PCK (Shulman, 1986).

The component of *learners' prior knowledge and misconceptions* specifically refers to a teacher's awareness of the knowledge from previous lessons that learners bring with them to the learning of a new topic or concept. This may include the knowledge that they acquire experientially and impulsively through everyday experiences (Rusznyak

& Walton, 2011). This knowledge includes leaners' pre-conceptions or misconceptions that influence the manner in which the learners interact with the new concept they are being taught.

2.6.4 Representations

Representations refers to knowledge of an array of methods used to represent content knowledge such as practical demonstrations, diagrams, analogies, and examples. Shulman (1986, p. 9) asserted that teachers "must have at hand a veritable armamentarium of alternative forms of representations, some of which derive from research whereas others originate from the wisdom of practice". In the teaching of physics, these representations may take the form of laboratory work, demonstrations, models, charts, diagrams, and scientific or mathematical equations (Akinyemi, 2016).

2.6.5 Conceptual Teaching Strategies

This component draws on the previous four components of TSPCK (Mavhunga & Rollnick, 2013) and refers to teachers' knowledge of a variety of effective instructional strategies for the teaching of particular concepts or topics. Knowledge of teaching strategies alone is not adequate for ensuring learner understanding, but "informed and thoughtful use in appropriate ways at appropriate times can influence student thinking and may well promote better understanding of science ideas" (Loughran et al., 2004, p. 18). Teachers with well-developed knowledge of this component for a particular topic will demonstrate an understanding of activities, discussions, questions, and representations that should be employed for the purposes of achieving conceptual understanding by learners (Mazibe, Coetzee, & Gaigher, 2018).

2.7 CAPTURING PCK

It has been observed that although a teacher may be able to teach a particular topic well, they are not always able to explain the reasoning behind the planning and execution of their lessons (Loughran et al., 2004). This could be due to a pragmatic approach when preparing lessons which does not expect of teachers to explain the reasoning behind their planning or the PCK employed to prepare their lessons (Kind, 2009). Capturing teacher PCK has thus proven to be difficult for many researchers. Teaching is a complex task with various forms of knowledge that are woven together for the culmination of a lesson. The ability of teachers to articulate the link between their knowledge and practice is often underdeveloped as a result of demands such as time, curricula, and learner performance (Loughran et al., 2004). Teachers' knowledge is thus elusive and tacit with no structure or language to adequately articulate it (Hume, 2010; Loughran et al., 2004; Pitjeng-Mosabala & Rollnick, 2018). PCK is also an internal construct (Baxter & Lederman, 2002) making it difficult for researchers to recognise and capture. The tacit nature of PCK posed a challenge to researchers as it would be little more than a theoretical construct if there was no way in which to concretely capture and portray it. Loughran et al. (2004) developed a tool to capture and portray PCK through research which had a group of experienced teachers discuss what they perceived as being the main ideas or concepts of a particular content area. A set of framing questions or prompts were created which would elucidate how they would go about helping their students to understand these ideas. From these findings, Loughran et al. (2004) developed a tool that they believed was capable of capturing, documenting, and portraying PCK which they named the Content Representation (CoRe) tool. This tool was developed based on a common belief among researchers that teacher PCK forms part of, and is visible in a teacher's approach to teaching a particular topic.

The CoRe tool developed by Loughran et al. (2004) contains eight questions known as prompts in a tabular format which probe various aspects of teacher knowledge related to a topic (see Table 2.1). This knowledge is regarded as reflecting the PCK held by the teacher. By codifying and categorising teacher knowledge within a topic, the CoRe is able to identify important aspects of the content that a teacher recognises and responds to in their teaching. The CoRe requires teachers to begin by first identifying important or key ideas related to a topic. This sheds light on the way in which teachers frame a particular topic and the ideas that teachers believe are valuable in helping learners to understand it.

Table 2.1: The CoRe template

Content Area	**Key Idea A**	**Key Idea B**	**Etc.**
What do you intend learners to learn about this idea?			

Why is it important for learners to know this?			
What else do you know about this idea (that you do not intend learners to know yet)?			
What are the difficulties/limitations connected with the teaching of this idea?			
What is your knowledge about your learners' thinking that influences your teaching of this ideas?			
Are there any other factors that influence your teaching of these ideas?			
What are your teaching procedures (and particular reasons for using these to engage with this idea)?			
Specific ways of ascertaining learners' understanding or confusion of this idea (include a likely range of responses).			

Source: Loughran et al. (2004)

The CoRe provides a means by which to capture TSPCK as opposed to general PCK (Lee & Luft, 2008). Loughran et al. (2004) asserted that no one CoRe is correct but that a variety of CoRes based on a particular topic are possible as different teachers conceptualise content in different but valid ways. This tool has been used by a number of researchers to capture PCK within specific science topics such as Chemical Equilibrium (Mavhunga & Rollnick, 2013), Amount of Substance (Padilla, Ponce-de-León, Rembado, & Garritz, 2008) and Graphs of Motion (Mazibe et al., 2018). The CoRe is regarded by Kind (2009) as being one the most useful techniques for eliciting and capturing teacher PCK. The CoRe has been used as one of the data collection tools for this study.

2.8 INTERPRETING THE CURRICULUM

Although teachers work within the framework of the same curriculum, they do not all implement the curriculum in the same way (Songer & Gotwals, 2005). There has been a growing trend of studies that investigates teachers' use and implementation of curricula (Bümen, Çakar, & Göğebakan-Yildiz, 2014; Remillard, 2005). Curriculum fidelity is one such focus which has sought to measure "how well a [curriculum] program is being implemented in comparison with the original program design" (Mihalic, 2002, p. 2). Teachers' knowledge in their field (referred to as subject-matter knowledge) (Carlsen, 1993; Roehrig & Kruse, 2005) and their pedagogical skill (Adams & Krockover, 1997; Shulman, 1987) influence their implementation of a curriculum. Remillard (2005) noted that many researchers are of the view that teachers are active interpreters of the curriculum resulting in different implementations in their own classrooms. Various factors such as the extent to which teachers regard the curriculum as a fixed representation of the enacted curriculum or whether interpretation of the concepts to be taught are needed influence the implementation of a curriculum. It is thus important to understand the purpose of a curriculum and what it serves to provide so as to understand why its contents are interpreted in different ways and the factors that influence these interpretations.

The process of instructional practice begins not with the designing of a lesson but with interpreting the expectations of the curriculum. The curriculum, often taking the form of a document, sets out the knowledge and skills learners are to acquire and can be seen as a blueprint for what is to be taught and learnt. But just like a blueprint for a house does not describe how each and every brick should be laid or what should be used to put them together, a curriculum does not provide a step-by-step guide to achieving learner understanding. If such a curriculum were to do so, this would undisputedly undermine the role of the teacher and their assumed ability to design effective lessons that are attuned to the context in which they teach and the unique learners whose tuition they are responsible for. This is often the case in "teacher-proof" curricula where teachers' ability to think through the complexities of the teaching and learning process is limited (Curtis & Carter, 2008). Therefore, implicit in the role of a teacher is their ability to interpret the expectations of the curriculum as well as determine the most appropriate and effective way of achieving these expectations. Du Plessis supported this idea, noting the following:

> [It is] during the implementation process [of the curriculum] that empowered teachers have to apply the appropriate curriculum skills … to ensure the correct interpretation and coverage of policy. (2005, p. 98)

During the planning phase of instructional practice, teachers interpret the curriculum by "critiquing and adapting existing curriculum materials to contextualise lessons and compensate for their deficiencies" (Beyer & Davis, 2012, p. 1) which arise as a result of curriculum material being designed for a wide audience and general contexts. This is particularly true for CAPS which is the curriculum used in all public schools throughout South Africa and thus is employed in a diverse range of schools. The need to use curriculum material in a flexible way that allows for teachers to adapt it to the needs, interests, and experiences of their own classrooms is important (Beyer & Davis, 2012). Teachers read and interpret curriculum materials in a discerning way, making use of their knowledge of students, pedagogy, and content, to identify strengths and weaknesses in the materials which determines how it will be used and adapted for instruction (Beyer & Davis, 2012). Ben-Peretz, Katz, and Silberstein (1982) referred to criteria employed by teachers to interpret the curriculum:

> Teachers need a rich repertoire of criteria for interpreting curriculum materials and revealing the possible educational opportunities embodied in them. A more refined and differentiated mode of teacher-thinking about curriculum could lead to a better grasp of the richness and complexity of the educational opportunities offered by curriculum materials. Metaphorically speaking, one may view the set of criteria teachers use for discerning characteristics of curriculum materials as a set of goggles. (p. 47)

This set of goggles can be understood as knowledge possessed by the teacher through which the curriculum is analysed and interpreted. Some of the categories used by Ben-Peretz et al. (1982) to classify the criteria according to which teachers interpreted a curriculum are: content; teaching strategy; level of difficulty; cognitive demand; and class management. The connection between curriculum interpretation and teacher knowledge is clear in Ross's statement:

> Teachers learn the curriculum requirements, apply pedagogical content knowledge, and plan meaningful activities for students during the implementation of a curriculum that they are simultaneously teaching and learning about. (2017, p. 3)

Pedagogical content knowledge forms part of a variety of resources that a teacher employs in the process of designing a lesson, shaping their instruction (Beyer & Davis, 2012).

This study holds that a teacher's interpretation of the curriculum is evident in their enactment of it during their teaching

The impact that teachers' PCK has on curriculum interpretation was observed in research conducted by Chen and Wei (2015) who studied discrepancies between the intended and enacted curriculum across three levels. These levels were teaching strategies, teaching objectives, and teaching activities. Seven distinct factors that led to these discrepancies were identified, one of which was PCK. Pedagogical content knowledge was found to have the largest influence across all three levels with its influence being observed in all six participants in terms of their teaching strategies which differed from teaching strategies suggested in curriculum materials used by the teachers.

Veal and Makinster (1999) have pointed out that PCK has a domain specific nature. Although the study conducted by Chen and Wei (2015) observed discrepancies between the intended and enacted curriculum, their study looked at chemistry teachers. The PCK applied by chemistry teachers cannot be assumed to be the same as that applied by a physics teacher. Both of these domains are usually taught by a single teacher in South African high schools as part of the subject Physical Sciences but their PCK employed would not be the same based on the topic they teach and the respective domain to which it belongs (physics or chemistry). This study sought to characterise the PCK held by teachers in a physics topic, specifically Faraday's law and its relation to their interpretation of the curriculum on this topic.

2.9 SUMMARY

Various authors have noted the difficult nature of the topic of Electromagnetism. This chapter began with a discussion of the findings of a study within the topic of Electromagnetism conducted by Coetzee (2018) which led to Faraday's law being the focus of this study. PCK as a knowledge base of teachers was described with Mavhunga and Rollnick's (2013) model of TSPCK discussed as a means to understand the PCK held by teachers in a particular topic. Lastly, the CoRe as a tool to capture teachers' PCK was discussed.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter presents a description of the research process that was undertaken to investigate the research questions. The process involved a systematic method to gather, interpret, and construct meaning from the data. Cooperrider and Srivastva (1987, p. 1) stated that "through our assumptions and choice of [research] method we largely create the world that we discover". As such, a discussion of the philosophical assumptions upon which this study lies and the methodology that guided it are presented. This chapter also describes the various stages of the research process which included sampling, data collection methods, and instruments used. The chapter ends with a discussion of how credibility and trustworthiness requirements were met.

3.2 RESEARCH QUESTIONS

Primary Research Question:

How can selected teachers' enactment of the curriculum on Faraday's law be understood in relation to their reported PCK?

Secondary Research Questions:

1. How can the curriculum on Faraday's law be characterised in terms of the topic-specific PCK components?
2. How can selected teachers' reported PCK about Faraday's law be characterised?
3. How do the teachers' presentation of lessons on Faraday's law align to the curriculum, or deviate from it?

3.3 RESEARCH PARADIGM

A paradigm acts as a particular perception of reality which is shared by a community of scientists which provides a model by which they could examine problems and find solutions (Thomas, 2010). A paradigm encompasses the fundamental aspects of reality by addressing assumptions regarding the researcher, the nature of reality (ontology), how nature can be known (epistemology), and the associated methodological tools and approaches used to solve problems (Maree, 2016). It thus acts as the lens through which we interpret our reality.

This study was conceptualised within the interpretivist paradigm. I am of the belief that humans continuously attempt to make sense of the world around them, and in doing so, they rationalise, justify, and provide meaning to everyday actions through their interpretations of their world (Babbie & Mouton, 2008). “Different people and different groups have different perceptions of the world” (Willis, 2007, p. 194) which lead to variable realities that consist of people’s subjective experience of the world. An interpretivist point of view was adopted for this study as it holds that reality is socially constructed (Thanh & Thanh, 2015) with the researcher being responsible for the interpretation of the reality. The reality in this study represented the teachers’ reported PCK and their interpretation of the curriculum.

Black (2006) affirmed the power of interpretivism to address the complexity and meaning of situations. This study assumed that a teacher’s interpretation of the curriculum and its expectations would be visible in their lesson presentations. Interpreting the words and actions of teachers throughout the instructional practice period would generate subjective meaning of their actions and thus their PCK that informs their interpretation of the curriculum. Schwandt (2000) explained that understanding the meaning of human action requires one to determine the intent behind those actions. This is achieved by “getting inside the head of an actor to understand what he or she is up to in terms of motives, beliefs, desires, thoughts, and so on” (Schwandt, 2000, p. 192). Pre- and post-interviews were used to gain a greater understanding of the teachers’ responses in their CoRe documents as well as their motives and actions during the teaching of their lessons on Faraday’s law.

The interpretivist paradigm has been criticised for its assumption that participants continually monitor their conduct and thus are aware of their intentions and reasons for their actions (Giddens, 1984). Lewis-Beck, Bryman, and Futing Liao (2004) made the case that reflection upon actions takes place only during retrospective inquiry whereby actions are queried. Post-lesson interviews were held with the participants to uncover the intentions behind their thoughts and actions during the presentation of their lessons to minimise the possibility of inaccurate assumptions being made.

3.4 RESEARCH METHODOLOGY

Research methodology is the systematic approach taken by a researcher in order to solve a problem and encompasses the procedures by which a researcher describes, explains, and predicts the phenomena being observed (Goundar, 2012). Various research methodologies exist due to a difference in the assumptions they make on how the world can be understood. These assumptions dictate the manner in which data is gathered and analysed and the extent to which findings can be generalised (Thomas, 2010). The nature of the research problem dictates the approach followed, which in this study was exploring teachers' interpretation of Faraday's law in relation to their reported PCK. As such, qualitative research was undertaken. Maree (2016) described qualitative research as research which seeks to gain a deeper understanding of a phenomenon. Chan and Hume (2019) found that the majority of research conducted on the nature of science teachers' PCK followed a qualitative approach, further supporting the qualitative approach taken in this study.

3.5 RESEARCH DESIGN

Case study design was adopted for this study due to the desire to gain a thorough and in-depth understanding of a number of cases within their natural contexts (Bromley, 1991). Case study research involves extensive data collection with multiple forms of data to provide detailed descriptions and in-depth information of a process or activity of multiple individuals which are bound by time and activity (Mills, Durepos, & Elden, 2010). In this study, the individuals were the teachers whose process of teaching and their interpretation of the curriculum were studied. To gain in-depth understanding of this process, multiple forms of data were collected which included document analysis, observations, and interviews to gather data for rich description. This allowed the participants to express the TSPCK they held in the topic of Faraday's law as well as their interpretation of the curriculum. Multiple-case design, as opposed to single case, was chosen for its ability to provide more extensive descriptions and explanations of the phenomenon being studied (Mills et al., 2010). Mills et al. (2010) acknowledged the disadvantage of single-case designs in that they may fall short in their representativeness. Multiple cases need to be studied to achieve a true reflection of the situation being studied. Although findings of case study research are limited in their generalisability, its advantage lies in the in-depth understanding of the case under study which resonates with a qualitative approach.

3.6 SAMPLING

Sampling in social research offers several advantages in terms of reducing both costs of data collection and the time required to collect and process data (Corbetta, 2003). In this study, I used convenience and purposive sampling. Etikan (2016) noted that convenience sampling is a technique used to select participants "where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to participate are included for the purpose of the study" (p. 2). Purposive sampling was used to select participants from the target population which consisted of South African Physical Science teachers from high quintile schools that were currently teaching Grade 11 Physical Sciences. Four Physical Sciences teachers were selected for this study. Although this is a relatively small sample size, it allowed for the in-depth interpretation of the participants' reality, in this case, their reported PCK, and interpretation of the curriculum. Apart from proximity, the need to be teaching Grade 11 at the time of the study, and the use of English as the language of instruction, no further requirements were used to exclude teachers from participating in this study. The sample thus used in this study consisted of Grade 11 Physical Science teachers from high quintile schools in the Tshwane municipality.

The biographical information of the four teachers selected as participants is provided in Table 3.1. Both Michelle and Tebogo came from school 1, while Sarah and Linda came from school 2.

Table 3.1: Teachers' biographical information

	Michelle	Tebogo	Sarah	Linda
School	1	1	2	2
Race	White	Black	White	White
Primary language	Afrikaans	Sepedi	Afrikaans	Afrikaans
Qualification	BEd	MSc & PGCE	BSc Ed & PGCE	BSc Hons & PGCE
Number of years teaching Physical Sciences	1	7	6	20

School 1 and 2 were well-resourced, English medium schools located in the Tshwane municipality and had many similarities with each other. Both schools were categorised as quintile five schools. The demographics of both school 1 and 2 comprised 90% African learners with the rest of the learners being mostly of White, Coloured, and Indian descent. These learners came from various socio-economic backgrounds. School 1 and 2 had between 1100 and 1200 learners in total. However, school 1 had an average of 20 learners per Grade 11 Physical Sciences class whereas School 2 had on average 14 learners per Grade 11 Physical Sciences class.

3.7 RESEARCH INSTRUMENTS

The data required for this study needed to reflect the PCK of the teachers and their interpretation of the curriculum. As such, suitable instruments for data collection that were used included the CoRe tool, lesson observations as well as pre- and post-interviews.

3.7.1 Curriculum Document of Faraday's Law

In order to explore the teachers' interpretation of the curriculum, it was necessary to know what the curriculum expects of teachers in the topic of Faraday's law. Page 87 and 88 of the curriculum document combined in Figure 3.1, which refers to the teaching of Faraday's law, thus also formed part of the data collected in this study. The analysis of these pages is discussed in Chapter Four. Data collected from these two pages was used to answer the first sub-question: How can the curriculum on Faraday's law be characterised in terms of the components of TSPCK?

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
3 hours	Faraday's Law.	• State Faraday's Law. • Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer • Use the Right Hand Rule to determine the direction of the induced current in a solenoid when the north or south pole of a magnet is inserted or pulled out • Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (Ø) passing through the loop is defined as: Ø = BAcosθ, where θ is the angle between the magnetic field B and the normal to the loop of area A • Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux • Calculate the induced emf and induced current for situations involving a changing magnetic field using the equation for Faraday's Law: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ where Ø=BAcosθ is the magnetic flux	**Practical Demonstration:** Faraday's law	**Materials:** Solenoid, bar magnet, galvanometer, connecting wires.	Stress that Faraday's Law relates induced emf to the rate of change of *flux*, which is the product of the magnetic field and the cross-sectional area the field lines pass through. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change. The directions of currents and associated magnetic fields can all be found using only the Right Hand Rule. When the fingers of the right hand are pointed in the direction of the current, the thumb points in the direction of the magnetic field. When the thumb is pointed in the direction of the magnetic field, the fingers point in the direction of the current.

Figure 3.1: The topic of Faraday's law in the curriculum document

3.7.2 The Content Representation (CoRe) Tool

The CoRe, discussed in Section 2.8 of the literature review, was created by Loughran et al. (2004) as "a research tool for accessing science teachers' understanding of the content" to be taught by eliciting "their understanding of important aspects of the content … that science teachers recognise and respond to in their teaching of such content" (p. 376). The CoRe tool has been used in many studies such as those conducted by Coetzee (2018), Mazibe et al. (2018), Barendsen and Henze (2019), and Juhler (2016). Thus it is regarded as a valid instrument for capturing teachers' PCK. The CoRe used in this study (See Table 3.2) required the participants to initially select key ideas within Faraday's law. The CoRe template in Table 3.2 comprises of eight questions originally designed by Loughran et al. (2004) to elicit participants' knowledge regarding the five components of TSPCK. The template provided space for the identification of four key ideas in Faraday's law, however, participants were informed that they could select as many key ideas as they felt necessary. Data collected from the CoRes were used to answer the second sub-question: How can selected teachers' reported PCK about Faraday's law be characterised?

Table 3.2: A Content Representation (CoRe) template

	Key Idea A	**Key Idea B**	**Key Idea C**	**Key Idea D**
1. Please fill in the key ideas on Faraday's law.				
2. What do you intend learners to learn about each key idea?				
3. Why is it important for learners to know this key idea?				
4. What else do you know about each key idea (that you do not intend learners to know yet)?				
5. What are the difficulties/limitations connected with teaching this idea?				

6. What is your knowledge about the learners' thinking that influences your teaching of these ideas?				
7. Are there any other factors that influence your teaching of these ideas?				
8. What are your teaching procedures (and particular reasons for using these to engage with this idea)?				
9. Specify ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).				

3.7.3 Pre-Interviews

In researching teachers' PCK in Graphs of Motion, Mazibe et al. (2018) found that despite efforts to explain to teachers how to complete the CoRe, participants still had difficulties filling it in, providing limited responses with not all the relevant information being supplied. Kind (2009) also noted that completing the CoRe may be seen as an intimidating process for a newly qualified teacher or a teacher that lacks confidence in their ability to teach. For this reason, the questions from the CoRe were also used as questions in a pre-interview held before the teachers taught their lessons on Faraday's law. Interviews provided the opportunity to ask questions that sought to clarify participants' answers in their CoRe in order to gain a more in-depth understanding of their PCK.

3.7.4 Observations and Field Notes

Observations of the participants' lessons were conducted during which field notes were taken. Field notes "aid in constructing thick, rich descriptions of the study context … and documents valuable contextual data" (Phillippi & Lauderdale, 2017, p. 381).

Observations of the participants' lessons were used to answer the third sub-question: How do the teachers' presentation of lessons on Faraday's law align to the curriculum, or deviate from it?

3.7.5 Post-interviews

Video recordings of the participants' lessons were reviewed during which questions were developed to corroborate the observations in terms of their curriculum interpretation. These questions sought to elicit the participants' understanding of the expectations of the curriculum as well as to gain knowledge as to why they may have deviated from or conformed to these expectations. Figure 3.2 provides an excerpt of the interview schedule used during Sarah's pre-interview. Post-interviews were used to corroborate the data collected during lesson observations to answer the third sub-question.

Interview schedule – Post-interview **Teacher:**______________________________ **Date:**___________________________
1. For how many years have you been teaching?
2. How many years have you specifically been teaching Grade 11 Physical Sciences?
3. Have you read page 87 and 88 from the CAPS document on Faraday's law before?
4. Did you go through these pages before planning and preparing for your lesson on Faraday's law?
5. What topic is taught before Faraday's law / Electromagnetism in the Gr 11 syllabus?
6. What topic is taught after Faraday's law / Electromagnetism in the Gr 11 syllabus?
7. Are there any topics in the Gr 10 and 12 syllabus that influence this topic and/ or the way you teach it?

8. Do any of these topic relate to Electromagnetism?
9. If so, how?
10. What do you understand by “State Faraday’s law”?
11. The CAPS document says: Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer. How would you describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer in words for learners?
12. You first introduced learners to magnetic flux before you introduced Faraday’s law. Why?

Figure 3.2: Excerpt of interview schedule used in Sarah’s interview

3.8 THE DATA COLLECTION PROCESS

This section discusses the process that was followed in order to obtain data that reflected the participating teachers’ PCK as well as their interpretation of the curriculum on Faraday’s law.

3.8.1 Completing the CoRes

CoRe templates were handed to the participants a minimum of two weeks before the presentation of their lessons. It was explained to them that the CoRe first required them to identify key ideas that are important to the teaching and understanding of Faraday’s law. Teachers were informed that the number of key ideas they wished to select was their choice. The teachers then needed to answer eight questions based on the key ideas they selected. The teachers were allowed to complete the CoRe in their own space and time and were informed that they could contact me should they be unsure of how to fill it in. Michelle and Tebogo’s (School 1) CoRes were collected one day prior to the presentation of their lessons. Sarah and Linda’s (School 2) CoRes were collected the same day they presented their lessons.

3.8.2 Pre-interviews

The participants' completed CoRes were reviewed and questions were developed that were used to gain greater clarity of their responses provided in their CoRes to provide a more complete description of their PCK in the topic of Faraday's law. These questions became part of the interview schedule that was used to conduct interviews held with the teachers before they taught their lessons on Faraday's law. The pre-interviews for Michelle and Tebogo were held earlier in the day on which they presented their lessons on Faraday's law. The pre-interviews for Sarah and Linda also took place on the morning of the day they presented their lessons. Both Sarah and Linda presented their lessons on the same day. All interviews were conducted on the school premises as chosen by the teachers. Voice recordings of the interviews were made and were transcribed verbatim for analysis later on (see Appendix IV).

3.8.3 Lesson Observations

Before the teachers started with their lessons, a voice recorder was placed on their desk to clearly capture their voice while they taught. I sat at the back of the classes out of direct sight of any learners so as not to distract them during their lessons. A video recorder was used to film the lessons. During this time, I took field notes to capture the various aspects of the lessons such as learner participation, content taught, and representations used.

3.8.4 Post-interviews

Questions based on the teachers' lessons were developed during and after observing the participants' lessons. These questions were used in an interview schedule for a post-interview that sought to clarify the thoughts and motivation behind the teachers' actions. The teachers' thoughts and actions are regarded as reflecting their interpretation of the curriculum by giving insight into what they believe was expected of them from a lesson on Faraday's law. Further questions were also used to probe the teachers' interpretation of the curriculum. Page 87 and 88 on Faraday's law in the curriculum document were provided to the teachers for them to refer to during the interviews. Post-interviews (see Appendix V) were held within one month of the teachers having taught their lessons on Faraday's law. The recordings of the interviews were transcribed verbatim and were used for data analysis (see Appendix VI). A summary of the data collection process is provided in Table 3.3.

Table 3.3: Summary of data collection process

Step No.	Process	Technique	Tool used
1.	Teacher prepares to teach Faraday's law.	Written response	CoRe
2.	Pre-interview held with teacher regarding responses given in the CoRe document.	Voice recording	Interview schedule
3.	Teacher presents the lesson on Faraday's law. Researcher observes the lesson.	Video Recording Observation	Field notes
4.	Post-interview based on the lesson presented and interpretation of the curriculum document.	Voice recording	Semi-structured interview schedule

3.9 DATA ANALYSIS

3.9.1 The Curriculum (CAPS) Document

An analysis of the curricular requirements on the topic of Faraday's law in the curriculum document was undertaken to determine the information conveyed in it and how it could inform teachers' PCK in terms of the five components of TSPCK (see Chapter Four). This was carried out by using the information provided in the expert CoRe to categorise the content in the CAPS document into these five components. The curriculum was also analysed in terms of information which is not evident in its content but regarded as important PCK by the expert CoRe.

3.9.2 The Expert CoRe

The data collected from the CoRes and pre-interviews was analysed by identifying responses that specifically pertained to information regarding a particular component of TSPCK. This was done using an expert CoRe (Appendix I). The expert CoRe used in this study is an adaption of an expert CoRe originally developed by Coetzee (2018) for the topic of Electromagnetism. Coetzee's expert CoRe was constructed by experienced science teachers and science education experts and serves as a representation of the PCK that is considered exemplary within each of the five components of TSPCK. Since this CoRe was specifically designed to represent exemplary PCK in Electromagnetism which covers various topics throughout the FET Physical Sciences curriculum, it was adapted for this study to reflect PCK specifically pertaining to Faraday's law taught in Grade 11. Content validation of the adapted expert CoRe was performed by the supervisors of this study who are experts in the field of Physical Sciences education to ensure that it accurately reflected the PCK pertinent to teaching Faraday's law. Three key ideas from Coetzee's expert CoRe were selected as key ideas in the topic of Faraday's law. These were: (i) 'The phenomenon of induction – the basic principle', (ii) 'Magnetic flux is the total magnetic field over an area perpendicular to the field', and (iii) 'Electromagnetic induction – Faraday's law'. The expert CoRe is included in Appendix I. The expert CoRe guided the analysis of the TSPCK held by each teacher by serving as a reference point during the assessment of the teachers' reported PCK from their CoRes and pre-interviews.

3.9.3 TSPCK Rubric

A rubric (see Appendix II) was employed to assess the level of TSPCK held by the participants. This rubric is an adaption of the rubric used by Mazibe et al. (2018) and is specifically used to assess the TSPCK in a physics topic which was reported in CoRe and pre-interviews. The rubric guides a researcher in rating and classifying a teacher's TSPCK according to different levels of competence. These levels have been assigned the terms: Limited (1), Basic (2), Developing (3), and Exemplary (4). Teachers are scored on each one of the five components of TSPCK. Each component has specific criteria which were used to determine the level of competency that a teacher has in that particular component of TSPCK. Table 3.4 is an excerpt of the rubric used in this study to score teachers knowledge of the component of *what is difficult to teach*.

Table 3.4: Excerpt of rubric used for scoring of reported PCK, for what is difficult to teach

Component	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
What is difficult to teach?	• No indication of concepts/ideas that are difficult to teach. • Reasons for the difficulty or gate-keeping concept are not specified.	• Identified broad concepts as difficult. • Reasons for the difficulties are not specific to the key ideas. e.g. "their science knowledge is poor".	• Identified specific concepts as difficult. • Outlined reasons related to learners' common difficulties.	• Identified specific concepts as difficult. • Outlined gate-keeping concepts as well as learners' misconceptions perpetuating the difficulties.

3.9.4 Lesson Presentations

The classification of the curriculum guidelines was used to analyse the participants' lessons of Faraday's law by comparing the PCK revealed in the teachers' lessons with the information contained in the curriculum. This analysis is presented in Chapter Six. During the post-interviews, participants were also asked to explain what each instruction in the curriculum document (Figure 3.1) for the section of Faraday's law expected of teachers. This data provided insight into their interpretation of the curriculum and thus the extent to which the teachers' lessons aligned or deviated with the expectations of the curriculum.

3.9.5 Comparing PCK and Curriculum Interpretation

In order to answer the primary research question, the teachers' reported PCK was compared with the data collected from their lesson observations and post-interviews. The enactment of the curriculum during the teaching of Faraday's law was taken as an indication of the teachers' interpretation of the curriculum and its expectations. Post-interviews were used to further probe the teachers' interpretation of the curriculum and corroborate the data collected from the lesson observations. The analysis specifically looked at whether the teachers presented their lessons in a similar way to the curriculum which suggested an interpretation of the curriculum at face value. Instances in which the teachers adequately interpreted the curriculum by incorporating adaptions or extensions to allow for conceptual understanding were also looked for. The teachers' interpretations of the curriculum were then compared to their reported PCK within each component of TSPCK.

3.10 ETHICAL CONSIDERATIONS

Rigorous ethical considerations were applied in this study by initially obtaining ethical clearance from the Ethics Committee at the University of Pretoria. This approval was received in July of 2019. Clearance to conduct research was then obtained in August of 2019 from the Gauteng Department of Education (GDE) to begin research (see Appendix VI). To comply with the ethical considerations set out by the University of Pretoria and the GDE, letters of consent were given to all parties involved to read and sign to indicate their agreement to participate (see Appendix VII to X). The letters of consent explained the purpose and potential benefits of the study as well as the forms of data collection that would be used. These were also verbally explained to the teachers, the primary participants of this study, before data collection was initiated. All parties involved were clearly informed that their participation was entirely voluntary and that they could withdraw at any stage.

The final research report uses pseudonyms for the participants and their schools so that they are not identifiable by the data collected from them. The names of the participants are only known to myself and the supervisors of this study. No risk of physical harm was present in this study and thus the participants were not remunerated for their participation.

This study is beneficial to the participants who will be given access to the final published research report. This will provide them with insight into the notion of PCK in the topic of Faraday's law which they could use to improve their own instructional practice. This has potential benefits for their schools in which teaching and learning could improve, thus also benefiting the learners.

3.11 CREDIBILITY AND TRUSTWORTHINESS

Credibility addresses the questions of: “Are the investigators observing or measuring what they think they are measuring?”, and “How congruent are the findings with reality?” (Merriam, 1998, p. 213). Addressing the former question, the line of questioning employed during the data collection process of this study as well as data analysis techniques used were derived from previous comparable research projects that have successfully utilised the same methods (Shenton, 2004). The CoRe document used to elicit the TSPCK of the teachers has been validated by various researchers such as Loughran et al. (2004), Mavhunga and Rollnick (2013), and Pitjeng-Mosabala (2014). The questions from the CoRe document also formed the basis of the questions used in the pre-interviews. To ensure that the findings of this study were congruent with reality, the data analysis and scoring of the participants’ TSPCK underwent expert validation through the regular reviewing and moderation by the supervisors of this study who are experts in Physical Sciences education. This ensured that there was agreement between the researcher and supervisors in terms of the TSPCK reflected by each teacher and their interpretation of the curriculum.

Trustworthiness of the research was achieved through triangulation which saw multiple forms of data being collected across the instructional practice period (Creswell, 2009). CoRe documents and pre-interviews reflected the teachers’ TSPCK in Faraday’s law while observations of the teachers’ lessons and post-interviews reflected the teachers’ interpretation and understanding of the expectations of the curriculum. The scores awarded to each teacher based on their reported PCK as well as the analysis of their interviews and lesson observations were reviewed by the supervisors of this study. In cases where a disagreement between myself and the supervisors arose in the score awarded, discussions were held in order to come to an agreement as to the score which best reflected the teacher’s level of reported PCK.

3.12 SUMMARY

This chapter began with a description of the research process that was undertaken to investigate the research questions. A discussion of the philosophical assumptions upon which this study lies and the methodology that guided this study was presented. This chapter also described the various stages of the research process which included sampling, data collection method, and instruments used. The chapter ended with a discussion of how credibility and trustworthiness requirements were met.

The next chapter undertakes an analysis of the section of Faraday's law in the curriculum in order to characterise the information in it which can be considered as informing a teacher's PCK on this topic.

CHAPTER FOUR: SCRUTINISING THE CURRICULUM

4.1 INTRODUCTION

This chapter undertakes an analysis of the topic of Faraday's law in the curriculum in order to answer the first sub-question: How can the curriculum on Faraday's law be characterised in terms of the TSPCK components? The TSPCK provided in the expert CoRe was used to explore the curriculum in order to characterise the information contained in this section which is regarded as informing teachers' knowledge in terms of the five components of TSPCK in Faraday's law. Each component is discussed in a separate section of this chapter.

4.2 CODES USED FOR REFERENCING

Figure 4.1 presents the contents on Faraday's law provided in the curriculum (DoBE, 2011) under the same headings that they appear in the curriculum. Figure 4.1 includes a schematic overview of the relevance of the five TSPCK components to specific parts of the curriculum. For ease of referencing in the sections that follow, the information included in the curriculum were allocated codes. For the curriculum, each column was assigned a letter to represent the column in which certain information is found. The columns and their codes denoted by a single letter are:

- **Content, Concepts & Skills**: C
- **Practical Activity**: P
- **Resource Material**: R
- **Guidelines for Teachers**: G

The number that appears after the letter refers to a specific point in that column.

Time	Topic Grade 11	Content, Concepts & Skills (C)	Practical Activity (P)	Resource Material (R)	Guidelines for Teachers (G)
3 hours	Faraday's Law	C1. State Faraday's Law. C2. Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer C3. 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 C4. Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (Ø) passing through the loop is defined as: Ø = BAcosθ, where θ is the angle between the magnetic field B and the normal to the loop of area A C5. Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change In magnetic flux C6. Calculate the induced emf and induced current for situations involving a changing magnetic field using the equation for Faraday's Law: $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ where ∅=BAcosθ is the magnetic flux	P1. **Practical Demonstration:** Faraday's law	R1. **Materials:** Solenoid, bar magnet, galvanometer, connecting wires.	G1. 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. G2. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change. G3. 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.

Curricular Saliency

Representations

Conceptual teaching strategies

Prior knowledge / misconceptions

Curricular Saliency

What is difficult to teach?

Representations

Figure 4.1: Content from page 87 and 88 of the (CAPS) curriculum document, with relevant TSPCK components indicated

For the expert CoRe, the information was also allocated a code beginning with an E, a second letter based on the key idea that it refers to, and a number which denotes the specific point referred to in the expert CoRe. The codes for the three key ideas are:

- **EA**: *The phenomenon of induction – the basic principle*
- **EB:** *Magnetic flux is the total magnetic field over an area perpendicular to the field*
- **EC:** *Electromagnetic induction – Faradays law*

4.3 CURRICULAR SALIENCY

Table 4.1 shows the information conveyed in the curriculum document (left-hand column) and the corresponding TSPCK identified in the expert CoRe (right-hand column) that it informs.

Table 4.1: Teaching sequence implied by the curriculum compared to the Curricular Saliency component according to the expert CoRe

Curriculum Content	Expert CoRe
C1. State Faraday's Law	EC3. Faradays law: $\varepsilon = -N/\Delta\phi\Delta t$
C2. Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer.	EA1. When moving a magnet and a conductor relative to one another, a current will be induced in the conductor.
C4. Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (ø) passing through the loop is defined as: ø = BAcosθ, where θ is the angle between the magnetic field B and the normal to the loop of area A.	EB2. Mathematical definition: $\phi = BAcos\theta$, where ϕ is the magnetic flux measured in weber, **B** is the magnetic field measured in tesla, **A** is the area vector perpendicular to the surface and θ is the angle between **A** and **B**. The area is often the cross-section of a coil.
C5. Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux. G2. 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	EC4. Lenz's law to determine the direction of the induced current.

solenoid (same direction as the magnet's field) to try to oppose the change.	
(No information provided in the section of Faraday's law in the curriculum)	EC29. Relate the energy conversion to the conservation of energy and the direction of the induced current and induced field.
C6. Calculate the induced emf and induced current for situations involving a changing magnetic field using the equation for Faraday's law: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$	EC3. Faradays law: ε=$-N/\Delta\phi\Delta t$
G1. Stress Faraday's Law relates induced emf to the rate of change of *flux…*	EB4. This idea forms the basis of Faraday's law where the rate of change of magnetic flux is an important concept. EC2. The magnitude of the induced current depends on the rate of change in the magnetic flux ($\Delta\phi/\Delta t$)
G1. … *flux,* which is the product of the magnetic field and the cross-sectional area the field lines pass through.	EA4. The definition of magnetic flux.
(No information provided in the section of Faraday's law in the curriculum)	EC7. The concept has a practical application in the principle on which a generator operates. Generators form part of the Gr 12 curriculum. EC8. To understand how AC current and DC currents are generated. EC9. To understand the way transformers work.
(No information provided in the section of Faraday's law in the curriculum)	EC3. Faraday's law: ε=$-N/\Delta\phi\Delta t$ o The meaning of the negative sign

Two key ideas according to the expert CoRe are evident in the contents of the second column of the curriculum entitled 'Content, Concepts and Skills'. These are: 'Magnetic flux' (C4), and 'Faraday law' (C1). The expert CoRe includes a third key idea of 'The phenomenon of induction – the basic principle' which includes a demonstration of induction. This key idea is regarded as only being present in a lesson if either induction as a phenomenon is discussed (such as how electricity is produced), or a demonstration of induction is performed before Faraday's law. This would allow induction to be introduced as a phenomenon in which current is generated without the presence of a power source which learners are not familiar with. The curriculum discusses a demonstration of induction (C2) only after it indicates that Faraday's law should be stated for learners (C1). Thus, such a demonstration would be used to demonstrate Faraday's law rather than to understand induction as a phenomenon.

Bullet C3 refers to the right hand rule (RHR) and could mistakenly be regarded by teachers as a key idea relating to Faraday's law as it is discussed among other concepts that need to be taught. The RHR is a skill used to determine the direction of the induced current and not a key idea.

Although Lenz's law is not mentioned by name in the curriculum, section G2 is an implicit statement of Lenz's law which is also found in point C5. The expert CoRe indicates that learners should know what the meaning of the negative sign in Faraday's equation means which relates to Lenz's law. This is not pointed out in the curriculum, thus, teachers would need the necessary knowledge to identify that this content refers to Lenz's Law. The curriculum also does not emphasise the induced magnet field whose direction determines the direction of the induced current, nor does it mention how Lenz's law is related to energy conservation principles. These are important ideas which are required for a conceptual understanding of the induced current and the RHR.

The contents of the 'Content, Concepts and Skills' column (see Figure 4.1) could be assumed by teachers as suggesting a sequence in which important ideas should be introduced to learners. This would see teachers beginning their lessons by stating Faraday's law and thereafter demonstrating induction. Coetzee's (2018) study noted the problematic nature of this implied sequencing in the curriculum. She found that pre-service teachers who attempted to teach Faraday's law without first providing an explanation of the idea of magnetic flux found that learners struggled to understand these concepts. These pre-service teachers elected to first teach Faraday's law as the curriculum presents "State Faraday's law" as its first point with magnetic flux only being discussed later on in C4.

The ordering of the bullets would also see learners being introduced to the RHR (C3) before understanding the relationship between the direction of the induced field and the induced current (related to Lenz's law) which is mentioned only later in bullet C5. The expert CoRe suggests rather that key ideas should be taught in the following order: (key idea A) 'The phenomenon of induction – the basic principle', (key idea B) 'Magnetic Flux', and (key idea C) 'Faraday's law'.

Points EC7, EC8, and EC9 of the expert CoRe indicate that learners should have an understanding of what the practical applications of Faraday's law are as well as how the topic relates to topics that learners will study in Grade 12. This gives a sense of the importance of the topic which is not pointed out in any way in the section of Faraday's law in the curriculum. Thus, teachers who have taught Grade 12 before may be more likely to recognise the relevance of Faraday's law than those who have not.

4.4 WHAT IS DIFFICULT TO TEACH?

The curriculum document does not explicitly indicate concepts that are difficult for teaching or learning. Rather, certain information provided in the curriculum under the heading of 'Guidelines for teachers' is regarded as informing teachers' knowledge of difficulties. This is due to the extent to which certain ideas are explained which suggests that it provides guidance to teachers on particular aspects of a topic that are regarded as difficult.

Table 4.2: Content that is difficult to teach alluded to in the curriculum compared to the component of What is Difficult to Teach according to the expert CoRe

Curriculum Content	Expert CoRe
G2. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change.	EC13. The directions of the induced current and induced field and how they depend on the direction of the flux and whether it is increasing or decreasing.
(No information provided in the section of Faraday's law in the curriculum)	EC12. Learners find it difficult to apply Lenz's law and the right-hand rule to determine the direction of the induced current.
(No information provided in the section of Faraday's law in the curriculum)	EB7. Learners do not understand how a surface area can be described by a vector.
(No information provided in the section of Faraday's law in the curriculum)	EB8. Learners' ability to visualise the vectors and angles in 3D is limited hence the inability to understand the relevance of or to determine the angles between the

	magnetic field and the area vector. This specifically impacts their ability to determine the angle needed to calculate magnetic flux.

The expert CoRe notes learners' difficulty in understanding the relationship between the direction of the induced field and the change in flux (EC13). This appears to be the only difficulty alluded to in the curriculum by its explanation of how they are related to each other (G1). Learners may still struggle to conceptually understand this relationship as the curriculum overlooks the role of energy and the application of prior knowledge to understand the direction of the induced current.

The expert CoRe notes that Lenz's law and the RHR may be difficult to apply (EC12). In my own experience, I have observed that learners are unsure of whether to point their thumb in the direction of the bar magnet's magnetic field or the induced field which the curriculum does not clearly describe. Another difficulty relating to the RHR stems from the sequencing of the content in the curriculum. The RHR is mentioned in the curriculum (C3) before the idea that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux (C5). This may lead to teachers and/or learners applying the RHR to the incorrect magnetic field if they were not yet taught about the induced field which opposes the change in flux. This uncertainty is further exacerbated by the fact that the curriculum does not state which magnetic field (the changing field or the induced field) to apply the RHR to.

Two difficulties regarding magnetic flux are mentioned in the expert CoRe but are not alluded to in the curriculum. These relate to learners' difficulty to understand area as a vector quantity (EB7), and learners' ability to visualise vectors in three dimensions which lead to difficulties in determining the angle required to calculate magnetic flux (EB8). This calls for teachers to have knowledge of effective representations to explain the concept of flux in order to address these difficulties.

4.5 LEARNERS' PRIOR KNOWLEDGE AND MISCONCEPTIONS

All content previously taught in the Physical Sciences curriculum is considered to be learners' prior knowledge, but the curriculum does not specify *what* prior knowledge is relevant to the learning of a particular topic such as Faraday's law. As a result, misconceptions related to learners' prior knowledge are not alluded to in the curriculum. Topics that learners have previously studied that contain pre-concepts that are essential for the understanding of Faraday's Law are Magnetism, Electric Circuits, and Energy (with regards to mechanical and electrical energy). These topics are taught in Grade 10.

Table 4.3: Prior knowledge available in the curriculum compared to the Prior Knowledge component according to the expert CoRe

Curriculum Content	Expert CoRe
Page 38 – Grade 10 topic of Magnetism	EB9. Magnetic field and magnetic field lines
Page 42 – Grade 10 topic of Electric Circuits	EC18. The concepts of current and emf EC5. The relationship between the induced emf (ε) and the induced current is given by $\varepsilon = IR$ where R is the total resistance in the circuit where the current is induced.
Page 58 – Grade 10 topic of Energy	EA9. Learners must already have been taught about mechanical and electrical energy
Page 86 – Use the Right Hand Rule to determine the magnetic field (B) associated with: (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid.	EC19. The Right Hand Rule from the topic of Electromagnetism.

The expert CoRe indicates that it is important for learners to understand magnetic fields and magnetic field lines (EB9). This knowledge is first introduced in Grade 10 when learners are taught the properties of magnetic field lines. This is particularly important for the understanding of the concept of magnetic flux.

From the Grade 10 topic of Electric Circuits, learners must understand the concepts of current, emf (EA18), and resistance, and how they are related by Ohm's law (EC5).

Unlike pre-concepts from the topic of Magnetism and Electric Circuits whose terms are mentioned in the section of Faraday's law, pre-concepts from the topic of Energy are not. The Law of Conservation of Energy is important for understanding the reason why the induced current is set up in a direction so as to oppose the change in flux. This is important for understanding Lenz's law. Learners also need to recognise that an energy conversion takes place during electromagnetic induction (EA9). Energy conversions, particularly in circuits, are not emphasised well enough in preceding parts of the curriculum.

The RHR could be considered as prior knowledge as learners are first introduced to the rule at the beginning of the topic of Electromagnetism in Grade 11 when induced magnetic fields are studied. However, the version of the RHR used to find the direction of the induced current is different from the first RHR learners are taught to find the direction of the induced magnetic field. This distinction is not made in the curriculum and could possibly confuse teachers and learners.

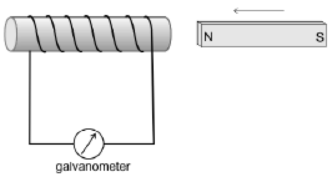
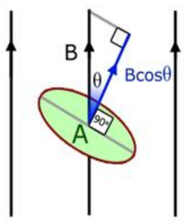
In terms of misconceptions, the curriculum does not explicitly discuss any that learners may have in the topics that form part of learners' prior knowledge for Faraday's law.

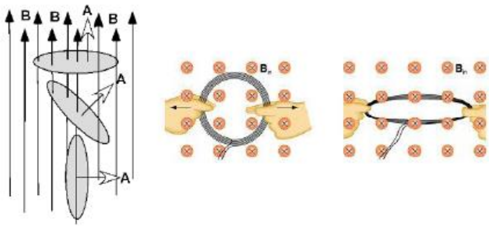
4.6 REPRESENTATIONS

The curriculum provides information regarding representations that teachers should use which can be found in the column of *Practical Activities*. Descriptions such as that of how to use the RHR are also provided and thus are seen as representations that must be shown to learners.

Table 4.4: Representations discussed in the curriculum compared to the Representations component according to the expert CoRe

<table>
<tr><th>Curriculum Content</th><th>Expert CoRe</th></tr>
<tr><td>P1. Practical demonstration
Faraday's law

R1. Materials:
Solenoid, bar magnet, galvanometer, connecting wires.</td><td>EA15. Use a representation with actual apparatus to show a coil connected to a galvanometer and a strong bar magnet.</td></tr>
<tr><td>C2. Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer.</td><td>EA15. Use a representation with actual apparatus to show a coil connected to a galvanometer and a strong bar magnet. Diagrams such as:

</td></tr>
<tr><td>G3. The directions of the currents associated magnetic field can all be found using 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 pointed in the direction of the magnetic field, the fingers point in the direction of the current.</td><td>EC31. Right-hand rule to determine the direction of induced current.</td></tr>
<tr><td>(No information provided in the section of Faraday's law in the curriculum)</td><td>EB14. Use a piece of cardboard (which depicts a particular surface) and a pencil perpendicular to the surface to explain the A-vector.</td></tr>
<tr><td>(No information provided in the section of Faraday's law in the curriculum)</td><td>EB27. Diagrams

</td></tr>
</table>

The curriculum states that a practical demonstration of Faraday's law must be performed for learners (P1) with bullet C2 indicating that teachers should explain the observations of this demonstration. It also includes the materials that are required for such a demonstration (R1). Teachers, however, will need to know how to set up the apparatus as well as what exactly should be explained and observed during this demonstration.

The RHR is a second representation discussed in the curriculum (G3) which the expert CoRe regards as an important demonstration (EC31). As previously discussed, the rule is not explained clearly enough which may result in it being applied to the wrong magnetic field.

Although magnetic flux is a new concept to learners, specific reference to representations that could be used to explain this concept are not mentioned in the curriculum. The expert CoRe includes diagrams that could be used to explain magnetic flux as well as to show how a change in flux could be brought about (EB27). These diagrams, together with the representation discussed in bullet EB14, would aid in addressing learners' difficulty in determining the angle required to calculate magnetic flux (EB8).

4.7 CONCEPTUAL TEACHING STRATEGIES

Conceptual teaching strategies require teachers to integrate their knowledge of the previous four components of TSPCK in such a way that they teach the learners in front of them in the most effective way. The curriculum provides little guidance on this particular component of TSPCK.

Table 4.5: Information informing conceptual teaching strategies conveyed in the curriculum document compared to the Conceptual Teaching Strategies component according to the expert CoRe

Curriculum Content	Expert CoRe
G1. 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.	EC1. Changing the magnetic flux (in any possible way) through a coil will result in induced current.
C2. Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer.	EA14. Perform actual demonstrations or use computer simulations such as PhET simulations showing how current is induced when there is relative motion between a magnet and a coil.
(No information provided in the section of Faraday's law in the curriculum)	EC29. Relate the energy conversion to the conservation of energy and the direction of the induced current and induced field.

Conceptual teaching strategies should take into account the context of the learning environment in terms of the type of learners present in the class, their specific prior knowledge, and the kind of questions to ask learners to elicit their understanding. The curriculum does not describe or prescribe a teaching strategy that teachers should follow. What is given in the curriculum, which should form part of a teacher's conceptual teaching strategies, are the representations of Faraday's law and the RHR. It also stresses that teachers should point out to learners that electromagnetic induction is based on the rate of change of flux. This seems to indicate that emphasis be placed on the fact that it is not a change in magnetic field in general that is required to generate an emf, but specifically a change in flux.

An important concept which is not emphasised in the curriculum is the relationship between the direction of the induced current and the induced field. A conceptual understanding of this is important for allowing learners to understand both the reason why the induced field opposes the change in flux as well as why the current is generated in a specific direction. This would also allow for an understanding of the concept on which the RHR is based.

4.8 SUMMARY

The contents of the curriculum suggest important ideas in Faraday's law which are similar to those in the expert CoRe. The ordering of the contents, however, could be interpreted as suggesting a teaching sequence of these ideas that is ineffective for conceptual understanding according to the expert CoRe. Important representations are mentioned in the curriculum but none are included for the concept of magnetic flux. Visibly absent from the curriculum, which the export CoRe indicates as important, is knowledge that will aid the conceptual understanding of the induced current. Lenz's law and the concept of an opposing induced magnetic field are not discussed. Pre-concepts from the topic of Energy relating to Lenz's law are also not referred to, even though other pre-concepts are, in the section of Faraday's law. While the curriculum does provide some content knowledge which could inform teachers' PCK for the component of *conceptual teaching strategies*, it does not indicate how teachers should involve learners or include strategies for eliciting learners' difficulties or misconceptions.

CHAPTER FIVE: REPORTED PCK

5.1 INTRODUCTION

This chapter presents an analysis of the data reflecting the reported PCK in Faraday's law of each participant in order to answer the second sub-question of the study: How can selected teachers' reported PCK about Faraday's law be characterised? The data analysed in this chapter was collected using CoRes completed by the teachers prior to the teaching of their lessons on Faraday's law, as well as pre-interviews held with each teacher.

This chapter begins with a description of what is considered as exemplary knowledge within each component of TSPCK. This is followed by a discussion on the process undertaken to analyse the data collected from the CoRes and pre-interviews as well as a summary of the scores of each component of TSPCK awarded to each teacher using a reported PCK rubric (see Appendix II). The chapter then continues with an analysis of each teacher's reported PCK, beginning with a table that summarises their reported PCK.

5.2 TSPCK COMPONENTS

This chapter sought to characterise the PCK held by the participants in Faraday's law. This PCK is referred to as the reported PCK and is the knowledge that is manifested by the teachers through non-observational means which included written and verbal means as reported in their CoRes and pre-interviews.

Below follows a discussion of what constitutes exemplary knowledge within each component of TSPCK as contained in the expert CoRe (see Appendix I). The discussion is intended to assist the reader in being aware of the type of information presented in the interpretation of the data and what would lead to a teacher being scored as having exemplary knowledge within a particular component.

5.2.1 Curricular Saliency

A teacher is scored as exemplary in this component for having knowledge of the key ideas and their related subordinate ideas within the topic of Faraday's law. They will also have revealed knowledge of sequencing of concepts for scaffolding to subsequent topics. This will stem from the recognition of the importance of these concepts and their interrelatedness within the curriculum.

5.2.2 What is Difficult to Teach?

A teacher is scored as exemplary if they demonstrate knowledge of difficult concepts and the reasons for misconceptions that perpetuate these difficulties.

5.2.3 Learners' Prior Knowledge and Misconceptions

A teacher is seen as having exemplary competence in this component for revealing knowledge about the prior knowledge or pre-concepts that learners should have in order to understand Faraday's law and misconceptions that arise from these pre-concepts.

5.2.4 Representations

A teacher is scored as exemplary if they demonstrate knowledge of a variety of effective representations that could be used to explain concepts and how they would be used to confront misconceptions and difficult concepts.

5.2.5 Conceptual Teaching Strategies

In this component, the consideration of the preceding components of PCK is important (Mavhunga & Rollnick, 2013). As such, a teacher is scored as exemplary if they demonstrate knowledge of activities to expose learner misconceptions and difficulties. The teacher will also demonstrate awareness of the interrelatedness of key ideas and how they will explain these key ideas, representations that they will employ as well as revealing strategies that are highly learner centred. Furthermore, a teacher will reveal knowledge of questions that will elicit learners' prior knowledge or understanding of what is being taught.

5.3 ANALYSIS PROCESS AND PRESENTATION

Analysis of the data for each teacher was conducted by initially identifying responses in each teacher's CoRe and pre-interview that related to a specific component of TSPCK. This categorisation of responses was guided by the expert CoRe which aided in the identification of responses given by the teachers that revealed knowledge regarding a certain component of TSPCK. These responses were summarised into a table which is provided in the analysis of each teacher's data that follows in this chapter. A discussion and analysis of these responses is also provided in this chapter. Since the expert CoRe served as an example of exemplary knowledge of the five components of TSPCK in Faraday's law, it was again used to gauge the reported PCK revealed by the teachers in terms of the quality. A discussion of this analysis is presented after the summary of each teacher's reported PCK. The rubric for Reported PCK (Appendix II) was used to assign a score to the TSPCK revealed by the teacher for each component. The scores are summarised in Table 5.1. Discussions were held between myself and the supervisors of this study when a difference in scoring arose for a particular component in order to reach an agreement for a score that most accurately reflected the TSPCK revealed by the teacher. Expert validation was thus achieved through the discussion and agreement of scores assigned.

Table 5.1: Summary of scores

TSPCK component	**Michelle**	**Tebogo**	**Sarah**	**Linda**
Curricular Saliency	3	3	2	2
What is difficult to teach?	3	3	3	3
Learners' prior knowledge and misconceptions	2	2	2	2
Representations	2	3	2	2
Conceptual teaching strategies	2	3	2	2
Average score	**2.4**	**2.8**	**2.2**	**2.2**

Legends used throughout the data presentation chapters are shown in the following examples:

- pre-interview, lines 12-15: pre-i, 12-15
- post-interview, lines 12-15: post-i, 12-15

5.4 CASE STUDY 1 – MICHELLE (SCHOOL 1)

Michelle is a Physical Sciences teacher who holds a BEd degree is science education. She was in her second year of teaching at the time of the study but it was her first year teaching Grade 11 Physical Sciences and so she had not taught Faraday's law before. Michelle's information from which her reported PCK was sought on Faraday's law is summarised in Table 5.2. Her completed CoRe and full interview transcript can be found in Appendix III and IV respectively. Michelle identified four key ideas in the topic of Faraday's law. Due to the manner in which Michelle filled out her CoRe document, the order in which she indicated she would introduce them did not follow the alphabetical order from key idea A to D. The key ideas that she selected are listed below in the order that she indicated she would introduce them in (pre-i, 11-16):

- Key idea A: Change in magnetic field
- Key idea C: Magnetic flux
- Key idea B: Induced emf
- Key idea D: Induced current

Table 5.2: Reported PCK based on CoRe and pre-interview for Michelle

Curricular saliency				
1.0 How were key ideas selected and sequenced?	• Selected key terms found in the definition for Faraday's law or factors that affect the induced emf (pre-i, 8-20).			
KEY IDEAS	**A: Change in magnetic field**	**B: Induced EMF**	**C: Magnetic flux**	**D: Induced current**
1.1 What do you intend learners to learn about each key idea?	• Relative motion between a conductor and magnetic field causes a change in magnetic field. • Change in magnetic field needed for emf to be induced (pre-i, 12)	• EMF generated by change in the magnetic environment. • Formula for calculating induced emf (pre-i, 14) • Factors affecting emf: number of windings, strength of magnet, rate of relative movement (pre-i, 15)	• Definition for magnetic flux. • $\Delta\Phi = \Phi_i - \Phi_i$ • Formula to calculate rate of change in magnetic flux.	• Direction of current (pre-i, 16). • Right-hand rule (pre-i, 15-16). • Lenz's law (pre-i, 16).
1.2 Why is it important for learners to know this key idea?	• Relevance of changing magnetic field in terms of emf generated. • No induced emf or induced current unless there is change in magnetic field (pre-i, 50-52).	• To understand how emf is generated in a conductor. • To understand Faraday's law and formula.	• Understand how it fits into Faraday's law. • Relation to the rate of change of flux. • To know how to calculate rate of change of magnetic flux (pre-i, 57).	• Understand that induced current flows in such a direction so that the magnetic field generated by the conductor will always oppose the change in flux.
1.3 What else do you know about each key idea (that you do not	• (Nothing identified in CoRe and pre-interview)	• (Nothing identified in CoRe and pre-interview)	• (Nothing identified in CoRe and pre-interview)	• Change in magnetic flux means a change in energy (Pre-i, 67)

intend learners to know yet)?				
1.4 Are there any other factors that influence your teaching of these ideas?	• Being a 1st year teacher affects how comfortable she is with the work. • Electrostatics and magnetism taught as separate concepts in Gr 10, now are combined in electromagnetism (pre-i, 71-73).	• (Nothing identified in CoRe and pre-interview)	• (Nothing identified in CoRe and pre-interview)	• (Nothing identified in CoRe and pre-interview)
Learners' prior knowledge and misconceptions				
2.1 What is your knowledge about the learners' thinking that influences your teaching of these ideas?	• Magnetism in Gr 10 related to Faraday's law (pre-i, 71). • Use pictures & examples for learner understanding (pre-i, 101-105).	• A lot of examples need to be done with learners (pre-i, 101-102). • Build an electromagnet in class (pre-i, 103-105).	• (Nothing identified in CoRe and pre-interview)	• Did not do Faraday's law and Lenz's law in university and therefore Michelle has not done practicals based on it (pre-i, 107-108).
What is difficult to teach?				
3.1 What are the difficulties/limitations connected with the teaching of this idea?	• (Nothing identified in CoRe) • Magnetic fields invisible, cannot be seen with the naked eye (pre-i, 76-79).	• (Nothing identified in CoRe and pre-interview)	• Cannot be seen with the naked eye (pre-i, 76-79).	• Concept of magnetic field opposing change in magnetic field (pre-i, 95-96). • Learners don't know which magnetic field to apply the right-hand rule to (pre-i, 96-97).

Conceptual teaching strategies & Representations				
4.1 What are your teaching procedures (and particular reasons for using these to engage with this idea)?	• Recap work done in previous lesson and ask learners questions based on this work. • Provide examples of electromagnetism in daily lives. • Draw scenarios relating to angle for calculating magnetic flux (pre-i, 90-91).	• (Nothing identified in CoRe). • Will introduce Faraday's law by writing the definition and then doing an example (pre-i, 158).	• Begin by explaining the use of electromagnetism in learners' daily lives. • Explain EM induction, then magnetic flux with help of notes.	• Will use a bottle as a solenoid and explain the RHR. • Send website links & videos if the RHR not understood, (pre-i, 161-162). • Show the different cases of a magnet entering or exiting a solenoid with the north or south facing solenoid (pre-i, 163-164).
4.2 Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses)	• Use media such as pictures and videos to see change in magnetic field.	• As an introduction to EM induction, build an electromagnet.	• Show videos and images to see magnetic flux because it can't be seen by the naked eye (pre-i, 82-85). • Use drawings to show different orientations of magnetic field like parallel and perpendicular to a coil (pre-i, 90-91).	• (Nothing identified in CoRe and pre-interview)

5.4.1 Curricular Saliency

Michelle's key idea of a 'Change in magnetic field' is similar to the key idea of 'The phenomenon of induction – the basic principle' in the expert CoRe. She stated in her CoRe (prompt 3) for this idea that she wants learners to understand the relevance of changing a magnetic field and its result of generating an emf. The 'Induced EMF' and 'Magnetic flux' also appear in the expert CoRe as key ideas. Key idea D of Induced current' is a subordinate idea to 'Induced EMF' according to the expert CoRe. Nevertheless, Michelle was aware that Lenz's law (which she included as part of key idea D) is a relevant idea in Faraday's law. In her pre-interview, she described the sequence in which she would introduce the key ideas:

> The first one will be the change in magnetic field so [that learners] understand you have to make a change in the magnetic field for EMF to be induced. And then after that I will do the magnetic flux and the rate that the magnetic flux changes to help them understand how it fits into Faraday's law. Then the induced EMF. ...And then afterwards I will do induced currents. (11-15)

In prompt 8 (key Idea C and D) of her CoRe, Michelle further explained the sequence of her lessons on Faraday's law. She wrote that she would first explain electromagnetic induction, magnetic flux, and then Faraday's law which revealed a sequence that would support conceptual understanding. It is evident that her key ideas A, B, and C and their sequencing closely align with the key ideas of the expert CoRe which suggests that the phenomenon of induction first be introduced to learners after which the concepts of magnetic flux and induced emf should be taught. She stated in her CoRe (prompt 2, key idea A) that she intended for learners to know how a change in magnetic field could be brought about by the relative movement of a solenoid and a magnet. Her intention may have been to introduce learners to the phenomenon of electromagnetic induction with a demonstration using a bar magnet and solenoid which she referred to in prompt 2. This is supported by her response to prompt 3 in which she noted that it is important to show learners such a demonstration so that they "understand the relevance and results [that] a changing magnetic field will have on the emf generated".

Michelle identified key ideas which also appear in the expert CoRe but did not refer to their importance as concepts that allow for scaffolding to subsequent topics in the Physical Sciences curriculum. Her sequencing of her key ideas did, however, suggest a logical progression that would assist learners' understanding of Faraday's law. Her knowledge of *curricular saliency* is therefore scored as Developing (3).

5.4.2 What is Difficult to Teach?

In her CoRe, Michelle discussed learners' difficulty in conceptualising ideas such as magnetic fields that are invisible (prompt 6, key idea A). This is a relevant difficulty as learners' prior knowledge of magnetic fields and misunderstandings thereof, would affect their understanding of magnetic flux. Michelle also spoke of learners' inability to distinguish between which magnetic field to apply the RHR to when determining the direction of the induced current, stating that "[learners] struggle to distinguish which north pole to place [their] thumb in" (pre-i, 97). This is a major difficulty faced by learners according to the expert CoRe.

A third difficulty discussed by Michelle related to Lenz's law. She noted that "learners struggle to understand the fact that the magnetic flux is being resisted" (CoRe, prompt 5, key idea D). Michelle's own understanding of why the magnetic flux is resisted may also have been restricted. In her pre-interview (67-68), she stated that learners do not yet know that "change in magnetic flux means changes in energy". This information was "googled" by Michelle and was originally written in her CoRe (prompt 4, key idea D) as "Lenz's law is an idea of conservation of *charge*", while in reality it is an idea of the conservation of energy. This indicates that she did not completely understand Lenz's law. Michelle's competence for this component of TSPCK was classified as Developing (3) as she identified major difficulties regarding magnetic flux and Lenz's law.

5.4.3 Learners' Prior Knowledge and Misconceptions

Michelle identified broad topics from previous grades as learner prior knowledge for Faraday's law. These were the Grade 10 topics of Electrostatics and Magnetism (prompt 6, key idea A and B). Although she presented them as topics that relate to Faraday's law, she did not suggest how they influence her teaching of the topic.

According to the expert CoRe, concepts such as current, emf, and resistance (from the topic of Electric Circuits taught in Grade 10) form part of learners' prior knowledge. Michelle instead identified Electrostatics from Grade 10 as influencing her teaching of Faraday's law although concepts from this topic do not relate to Faraday's law. This was Michelle's first year teaching Electromagnetism which may account for her unfamiliarity with the topic and ability to specifically identify the necessary pre-requisite knowledge that learners should have to support their understanding of Faraday's law.

Michelle did not reveal that she was aware of possible misconceptions that learners may have in the topic of Faraday's law. Only a general difficulty regarding learners' inability to visualise concepts that are invisible such as magnetic fields was discussed in her CoRe (prompt 6, key idea A). Following that Michelle identified broad topics as prior knowledge while she lacked knowledge of particular misconceptions in the topic of Faraday's law, her knowledge of learners' prior knowledge is scored as Basic (2).

5.4.4 Representations

Michelle expressed the importance of using representations during the teaching of Faraday's law stating that "if [learners] just read through the content, [they're] not going to understand" (pre-i, 102-103). Michelle explained in her pre-interview (90-91) that she would draw diagrams in her lesson for magnetic flux for the three different scenarios in which the magnetic field lines could be parallel, perpendicular, or at an angle to the normal of the loop. Michelle indicated in her CoRe (prompt 2, key idea D) and pre-interview (15-16) that she will use the RHR and Lenz's law to explain the direction of the induced current although she did not describe how she would demonstrate this.

For Faraday's law, Michelle described a representation in which she would use a magnet and a solenoid to explain the law. She mentioned that she would move the magnet close towards the solenoid to explain how the magnetic field can change in the solenoid. This demonstration is not entirely sufficient for demonstrating Faraday's law as it can only be used to explain how magnetic flux changes through the solenoid. This would not allow learners to visually see the induction of an emf or current without the presence of a galvanometer. This would lead to Michelle providing a verbal explanation of what learners would see and the various factors that would affect the magnitude of the induced emf instead of providing visual proof. Although Michelle identified important representations regarding magnetic flux, she inadequately described the use of representations to explain the RHR and Faraday's law. As a result, her competence for this component of TSPCK is scored as Basic (2).

5.4.5 Conceptual Teaching Strategies

Michelle's responses to prompt 8 in her CoRe indicated that her conceptual teaching strategy placed emphasis on the sequence of her lessons on Faraday's law and the order in which she will introduce concept. She was aware that revising content taught in a previous lesson is important for ascertaining learners' understanding, but the questions that Michelle planned to ask learners would require learners to remember what they were taught instead of their understanding of the content. She stated that she would ask learners: "Can you remember what the different types of conductors [are]?" She also indicated that she would ask: "How [do the different conductors] relate to Faraday's law with the rate of flux?" (pre-i, 155) as part of revision, yet the concept of Faraday's law would not yet have been introduced at that point.

Michelle's primary focus for the teaching of her key ideas 'Magnetic flux' and 'Induced emf' revolved around their formulas and learners' ability to calculate these values. When asked in her pre-interview what she intends for learners to know about these concepts, she stated that it is to know how to calculate it using their formulas (132 & 137). The concept of flux was poorly developed in Michelle's mind which is evident from her pre-interview when asked what magnetic flux is:

> The textbook defined it as the formula but then I did a bit of research and they say it's the number of magnetic field lines moving through an area so that's how I explain it to the learners as well. (39-41)

This may account for her providing only the formula to calculate the *change* in flux (prompt 2, key idea C) with no indication in her CoRe or pre-interview of whether she intended for learners to know how to calculate magnetic flux or the factors which affect its magnitude. This could indicate a gap in her content knowledge regarding this concept.

Michelle was aware of her lack of knowledge and teaching experience and how they influence her teaching. For prompt 7 in her CoRe, (prompt 7, key idea A) she stated:

> I am a first year teacher. I haven't taught the topic. I think that is a major influence on how comfortable I am with the work and how to explain it so that the learners can understand it to the best of their ability.

Her transmission approach to teaching, which is characteristic of novice teachers (Childs & McNicholl, 2007; Geddis et al., 1993), is highlighted in her pre-interview statements:

> [I] planned to teach Faraday's law starting with the definition. (134-345)

> My planning just consists of giving them the definition [and] doing an example on the board. (158-159)

Michelle's conceptual teaching strategy is characterised by the content which she will teach and the order in which she will teach it. Thought was not given to how she would explain each key idea in a manner that would allow for scaffolding of concepts and questions that she could ask to ascertain learners' understanding or misconceptions of the content. She also did not indicate how learners would be involved in her lesson. Her knowledge of *conceptual teaching strategies* was thus scored as Basic (2).

5.5 CASE STUDY 2 – TEBOGO (SCHOOL 1)

Tebogo holds an MSc in Applied Radiation Science as well as a Post Graduate Certificate in science education. He has been teaching Physical Sciences for seven years and had also taught Grade 11 for the same number of years. Tebogo was thus familiar with teaching the topic of Faraday's law. His completed CoRe and full interview transcript can be found in Appendix III and IV respectively. He selected three key ideas in the topic of Faraday's law which are listed below in the order that he indicated he would introduce them:

- Key idea A: Understanding electromagnetic induction
- Key idea B: Magnetic flux
- Key idea C: Calculations of emf

Table 5.3: Reported PCK based on CoRe and pre-interview with Tebogo

Curricular saliency			
1.0 How were key ideas selected and sequenced?	• Introduce key ideas in the following order: Electromagnetic induction, Magnetic flux and lastly, Calculations on emf (pre-i, 5-7).		
KEY IDEAS	**A: Understanding electromagnetic induction**	**B: Magnetic flux**	**C: Calculation of emf**
1.1 What do you intend learners to learn about each key idea?	• Understand how the emf is induced. • Understand how to increase the [magnitude of the] emf.	• What a magnetic flux is and, • How it can be calculated.	• Understand how to calculate the emf with a change in: - Flux - Field - Area - Time
1.2 Why is it important for learners to know this key idea?	• It will help learners understand how electricity is generated. • To understand the relationship between magnetism (from Gr 10) and electricity (pre-i, 19-20). • To understand how generators operate (pre-i, 15-16). • To be able to calculate the magnitude of current induced using ε = I.R (pre-i, 82-83).	• It will help learners to link the magnetic field and magnetic flux.	• Key skill in Physical Sciences is linking theory and calculations which help learners understand better. • Be able to make calculations solving for different variables in the formula of Faraday's law, not only emf (pre-i, 40-50). • Be able to calculate emf for changes in flux due to change in area and orientation of loop, and strength of B field (pre-i, 56-60).

1.3 What else do you know about each key idea (that you do not intend learners to know yet)?	• Electromagnetic induction is used in transformers. • AC & DC [motors and generators] use electromagnetic induction.	• Faraday's first and second law.	• (Nothing identified in CoRe or pre-interview)
1.4 Are there any other factors that influence your teaching of these ideas?	• There should be resources to help learners view the difference between flux and magnetic field.	• The magnetic flux and the change thereof should be fully explained, as it might make it difficult for the learners to understand the induction of the electromagnet.	• Revise how to convert units as learners forget (pre-i, 66-68).
Learners' prior knowledge and misconceptions			
2.1 What is your knowledge about the learners' thinking that influences your teaching of these ideas?	• Learners don't like the theory, they just want to calculate. • Learners never thought a magnetic field would have quantity (magnitude).	• To learners, flux should always be zero. • Learners must know what the magnetic field and the area are (pre-i, 107-108).	• Learners don't expect to calculate anything other than the emf. • Magnetic flux and the change in flux must have already been taught before electromagnetic induction (pre-i, 113-114).
What is difficult to teach?			
3.1 What are the difficulties/limitations connected with the teaching of this idea?	• Learners always confuse magnetic flux and magnetic field.	• Learners always struggle to determine the change in flux.	• The angle associated with the formula $\Phi = B.A\cos\theta$.

Conceptual teaching strategies & Representations			
4.1 What are your teaching procedures (and particular reasons for using these to engage with this idea)?	• Revise what a magnetic field is. • Learners should understand the difference between the: - Current carrying conductor - Solenoid	• Magnetic flux is through the surface, and there is an angle to the normal of the surface and the magnetic field.	• Learners should start with learning how to calculate: 1. Magnetic flux 2. Change in magnetic flux 3. Emf In that order.
4.2 Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses)	• By using different resources where they could see what a magnetic field is, and how we use it to determine the flux. • Show that a galvanometer deflects in different directions based on relative motion of a magnet and a coil (pre-i, 101-103).	• (Nothing identified in CoRe or pre-interview)	• (Nothing identified in CoRe or pre-interview)

5.5.1 Curricular Saliency

Tebogo's key idea A of 'Understanding electromagnetic induction' closely resembles the expert CoRe's key idea of 'The phenomenon of induction – the basic principle'. He indicated that this key idea included having leaners understand how an emf is induced (prompt 1, key idea A) as well as observing the deflection of a needle of a galvanometer (pre-i, 101-103). Key idea B and C of 'Magnetic flux' and 'Calculation of emf' respectively, also appear to be the same as the expert CoRe's key ideas B and C. The sub-ordinate idea of Lenz's law, however, was not mentioned in his CoRe or pre-interview.

Tebogo indicated that he would introduce the concept of electromagnetic induction before the concept of magnetic flux because in his view, it leads to the understanding of magnetic flux (pre-i, 5-6). This sequencing of key ideas was based on Tebogo's belief that learners first need to understand where the phenomenon of electromagnetic induction can be observed in our everyday lives with regard to electricity generation (prompt 3, key idea A) so that they understand the significance of studying electromagnetic induction.

> Learners need to first link the topics we do in class with the outside world. I normally used to tell them, 'OK tell me how is electricity produced?' They all tell you until where electricity is produced but they don't tell you what the generator does which is actually important which is where we have the electromagnetic induction. (13-16)

Tebogo gave attention to the order in which he would introduce concepts in his lesson. He explained that he had a 'small map' that guided his lesson and the sequencing of its related concepts. He stated:

> That for us to be able to start to say that we have [electromagnetism] that was induced, there was a flux, there was a field and before we had the field we had the area that had the non-contact force. (29-31)

This thought process saw Tebogo taking a reverse approach in which he worked backwards from the concept of electromagnetic induction to identifying underlying concepts that build upon each other and are interrelated.

Tebogo also indicated that the relationship between induced emf and current in a circuit is important. It can be deduced from his CoRe responses (prompt 4, key idea A) that he was aware of the importance of this relationship and how it lays the foundation for the progression towards subsequent topics. He mentioned in his CoRe (prompt 4, key idea A) that learners do not yet know that AC and DC use electromagnetic induction. This is presumably in reference to generators that learners study in Grade 12, a grade that Tebogo was also teaching at the time. He further revealed knowledge of electromagnetic induction and its use in transformers which is a topic related to Faraday's law and electromagnetism but not included in the CAPS curriculum for Physical Sciences.

Tebogo's responses in his CoRe and pre-interview suggest that his competence in this component of TSPCK is Developing (3) when compared to the TSPCK rubric, as he identified important key ideas. He also expressed a logical sequence for introducing concepts that allowed for scaffolding to subsequent topics. However, he did not mention teaching the important sub-ordinate idea of Lenz's law which is discussed in the curriculum although not by name.

5.5.2 What is Difficult to Teach?

The difficulties identified by Tebogo mostly revolved around learners' mathematical and reading abilities. In performing calculations for flux, he mentioned in his pre-interview (195-197) that learners do not remember how to convert units such as centimetres or millimetres squared to metres squared. This difficulty is not unique to the topic of Faraday's law and is usually easily addressed with revision of units and conversion factors.

He also mentioned in his pre-interview that learners do not realise that different variables in the formula for magnetic flux can experience a change which could create an induced emf as learners tend to focus on the idea of change in flux as a whole, and not what variable may have caused the change in flux.

> So a learner will only cram one way of calculating the emf not knowing that the angle can change, the field can change and also the area can change. They will only stick to one formula that I need to get the flux using this equation and then I get that change in flux, substitute it and I'm done. (38-42)

This misperception among learners of the type of calculations they could be expected to do would be addressed by Tebogo by having learners perform a number of different calculations on change in magnetic flux (pre-i, 113-114). He also expressed that if he were to set up a test on Faraday's law, he would include a question that would require learners to solve for a variable other than induced emf using Faraday's equation "just to change things around" (pre-i, 247).

Confusion between the words parallel and perpendicular when referring to the orientation of the magnetic field to the loop were also regarded as a difficulty by Tebogo, stating that learners are unable to interpret the correct angle needed for calculating magnetic flux. This relates to learners' limited ability to visualise in three dimensions and is considered a major difficulty according to the expert CoRe.

Tebogo mentioned that learners find it challenging to apply the RHR correctly for current-carrying conductors (presumably straight conductors) versus solenoids. This is an important difficulty to be aware of as it could pose a major challenge to learners later on when they need to apply the rule to solenoids in order to determine the direction of the induced current. The expert CoRe notes learners' difficulty in applying Lenz's Law and the RHR as learners tend to be unsure of which magnetic field to use when they apply this rule. This difficulty could be further compounded if the rules for straight conductors versus solenoids are confused by learners.

In terms of the TSPCK rubric, Tebogo's knowledge of *what is difficult to teach* was scored as Developing (3) as he identified major difficulties concerning learners' ability to determine the correct angle required to calculate magnetic flux and how to apply the RHR. He also recognised minor difficulties concerning learners' misperceptions of the kind of calculations they are expected to do.

5.5.3 Learners’ Prior Knowledge and Misconceptions

Tebogo demonstrated knowledge of prior topics in previous grades upon which the topic of Faraday’s law is built. In discussing Grade 9 content in his pre-interview, he noted that “we just teach them that we have different types of power stations. In Grade 10 we only focus on the circuits. And in Grade 11 that’s where we just do [electromagnetic induction]” (72-73).

Tebogo indicated that magnetism is an important topic in the understanding of electromagnetism. He stated that:

> We should go back to magnets because a learner needs to know that there is a magnetic field. Because we link the field [to electromagnetic induction] … we talk a lot about the field but the learner has to understand where the field comes from. (pre-i, 95-97)

He therefore planned to revise certain aspects of the topic of Magnetism such as the strength of magnets and their poles (pre-i, 100), before teaching them about magnetic flux. It is evident from his responses that he regarded magnetism as a topic often misunderstood by learners. He stated in his CoRe (prompt 5, key idea A) that learners always confuse magnetic flux and magnetic field, further elaborating in his pre-interview that this confusion arises due to the words “magnetic field” being used to define the concept of magnetic flux (pre-i, 155). This is similar to the misconception stated in the expert CoRe regarding learners’ inability to understand that field lines are imaginary lines used as a pictorial aid to understand magnetic fields while magnetic flux is an actual physical quantity. When probed further in his pre-interview regarding other misconceptions learners may have in the topic of Faraday’s law, he identified difficulties rather than misconceptions. These difficulties were discussed in the previous section.

Tebogo’s knowledge for this component of TSPCK has been scored as Basic (2). His CoRe and pre-interview responses only referred to concepts from the topic of Magnetism as being important prior knowledge for the understanding of Faraday’s law. In terms of misconceptions, Tebogo only revealed knowledge of one.

5.5.4 Representations

For his key idea of 'Understanding electromagnetism', Tebogo stated that he would use different resources to show learners what a magnetic field is and how it is used to calculate magnetic flux. He discussed in his pre-interview (100) aspects of magnetism that should be reviewed with learners such as the strength of magnets and their poles but did not elaborate what resources he would specifically use to represent these aspects.

While discussing magnetism as a topic that needed to be reviewed before electromagnetic induction, he spoke of the result of reversing the poles of a magnet and its effect on the induced current suggesting a possible representation to be used in his lesson. He stated:

> We can change the relative motion of the coil and the magnet by changing the poles. The galvanometer can face the opposite direction or can face the other direction. If we make it south the galvanometer will go the other way. (100-103)

It is possible that this representation would be used by Tebogo to demonstrate the phenomenon of induction. Tebogo's response refers particularly to the materials of a magnet and a galvanometer that are needed to perform such a demonstration. He also discusses an important observation which learners should make from this demonstration. These apparatus and the observation regarding the deflection of the needle of a galvanometer are included in the expert CoRe as well.

A practical demonstration to show learners how to determine the angle that is required for calculating magnetic flux was discussed by Tebogo in his pre-interview (179-183). He described having learners use a pen to pierce through a piece of paper to understand the normal of the conducting loop and then using a ruler to represent magnetic field lines to allow learners to visually determine the angle. The importance of performing a practical demonstration was also noted by Tebogo as a means of addressing learners' confusion between the words 'parallel' and 'perpendicular' when referring to the orientation of the loop to the magnetic field in questions (174-180).

Tebogo mentioned teaching learners the RHR in his pre-interview. He indicated that he would introduce it to learners in a method that would allow for scaffolding of concepts by first showing learners how to apply the RHR to straight conductors before applying to a solenoid:

> I start first with the simple thing, the current carrying conductor. They will have the pen in their hand. I will start teaching them how the current is moving, where the field is facing. Once they know those directions, I will start teaching them the right hand rule. ...But we have to start with that simple one, they know that if I have the pen in my hand, the coil will be represented by my fingers, the thumb is always pointing northwards. (138-145)

Tebogo's representations took into account demonstrating the phenomenon of electromagnetic induction which lies at the foundation of Faraday's law. He also carefully selected representations to enable him to address learners' difficulties with concepts such as magnetic flux and the angle needed to calculate it. Tebogo's knowledge of this component has been scored as Developing (3) based on the TSPCK rubric.

5.5.5 Conceptual Teaching Strategies

Tebogo's conceptual teaching strategy included revising learners' prior knowledge that was important for understanding Faraday's law and the concepts related to it, as well as addressing difficulties and misunderstandings with the topic.

In his pre-interview, he explained that his strategy for introducing the topic of Electromagnetic Induction begins with asking learners how electricity is produced because "learners need to first link the topics we do in class with the outside world" (13). This discussion would provide him with the opportunity to link the previous topics of magnetism and electricity that learners studied in Grade 10 to the idea of electricity production (19-21).

He had a clear idea in his mind of how the concepts in Faraday's law related to each other which led him to introducing them in a particular order to allow for conceptual understanding. He had chosen to begin discussing the idea of electromagnetic induction first before the concept of magnetic flux as "it leads to [learners] understanding the flux" (5-6).

In his CoRe (prompt 7, key idea B) Tebogo wrote: "The magnetic flux and the change thereof should be fully explained, as it might make it difficult for the learners to understand the induction of [electromagnetism]". This suggests that Tebogo regards magnetic flux as an important concept for learners to understand and that his lesson would ensure that learners understand the relationship between induced emf and rate of change of flux.

Tebogo planned to address a misconception held by learners regarding magnetic field lines as imaginary lines as opposed to magnetic flux as an actual physical quantity during his lessons. In his pre-interview, he stated:

> I will say the field is moving perpendicular but that is not the flux, the flux will be the one that we calculate using the surface area and the field passing through the surface area so that they understand I don't have the flux here, I will only have it if I calculate it. (157-160)

Concern was raised by Tebogo over learners' narrow view regarding calculations and the belief that they will only be expected to calculate the subject of the formula such as magnetic flux or emf, and not any of the other variables present in the formula (pre-i, 40-42). He indicated that he would address this incorrect belief by stressing the different variables that appear in an equation (45-48) and having learners perform multiple calculations of magnetic flux whereby in each calculation a different variable is changed.

> I normally teach these things in parts. We usually start a simple thing of calculating the flux. With a straight forward only change in the angle. Like maybe calculate the flux of this square loop when the angle of the field to the normal of the surface area is maybe fifty degrees. So then the learner first understand[s] just how to do field times area times cosTHETA. Then later on we'll change maybe magnetic field. After that maybe we'll change the area and then after that we'll change the angle. (55-61)

As part of revising work that he had taught in class to determine learners' understanding thereof, Tebogo described what he called a "throwback Thursday" in which he would, on a random Thursday during class, return to a particular topic such as electromagnetic induction and ask learners various questions:

> First of all what is electromagnetic induction? We start there just to gauge [learners'] understanding to see if they only relied on the notes or what they read. I will say explain it to me in your own words. Who remembers Faraday's law? Who can tell us the equation? Write it on the board. (234-236)

This form of testing allows learners to be actively engaged in the lesson while also allowing for immediate feedback by Tebogo to address any misunderstandings learners may have regarding the topic.

Tebogo's teaching strategy included revising content that plays an important role in understanding the topic of electromagnetism. He also took into account learners difficulties with calculations and planned to address these during his lesson. Although his method of testing learners understanding of the topic of Faraday's law saw learners engaging in the lesson, he did not express how he would determine their understanding while teaching the topic and the type of questions he would ask regarding the representations he would use. His knowledge of this component has been scored as Developing (3).

5.6 CASE STUDY 3 – SARAH (SCHOOL 2)

Sarah holds a BSc degree with a specialisation in science education. She had taken Physics to year 1 and Chemistry to year 3 at university. She has been teaching Physical Sciences for six years and had taught Grade 11 Physical Sciences for five years at the time of this study. Her completed CoRe and full interview transcript can be found in Appendix III and IV respectively. She selected two key ideas in the topic of Faraday's law which are listed below in the order which she indicated she would introduce them:

- Key idea A: Magnetic fields
- Key idea B: Magnetic flux

Table 5.4: Reported PCK based on CoRe and pre-interview with Sarah

Curricular saliency		
1.0 How were key ideas selected and sequenced?	• Selected ideas that relate to magnetic flux (pre-i, 7-8). • Will first introduce Magnetic fields, then Magnetic flux (pre-i, 10-11), then Faraday's law (pre-i, 21-22).	
KEY IDEAS	**(A) Magnetic fields**	**(B) Magnetic flux**
1.1 What do you intend learners to learn about each key idea?	• Magnetic fields always have a north and a south pole. • Magnetic field lines exist around magnets.	• It is the amount of magnetic field lines perpendicular to the area of the coil of conductor. • Change in magnetic flux can induce current (emf). • Magnetic flux can change because of change in magnetic field strength.
1.2 Why is it important for learners to know this key idea?	• Learners must understand that magnetic field lines are imaginary lines in order to understand how a coil can move through it.	• Faraday's law is based on change in magnetic flux. If learners don't understand the term magnetic flux, they won't understand how it can create an emf (current).
1.3 What else do you know about each key idea (that you do not intend learners to know yet)?	• (Nothing identified in CoRe or pre-interview)	• It is the basis for the working of motors and generators (Gr 12 work).
A4. Are there any other factors that influence you teaching of these ideas?	• (Nothing identified in CoRe or pre-interview)	• Sarah claimed that her limited knowledge influences her teaching and therefore she has to prepare a lot more and watch videos.

Learners' prior knowledge and misconceptions		
2.1 What is your knowledge about the learners' thinking that influences your teaching of these ideas?	• Learners need to see where these topics are used in everyday life for them to understand it better. So it is necessary to use real life examples.	• (Nothing identified in CoRe or pre-interview)
What is difficult to teach		
3.1 What are the difficulties/limitations connected with the teaching of this idea?	• Because magnetic field lines are imaginary lines, some learners find them difficult to imagine.	• It is only a change in magnetic flux that can create a current. • Determining the angle needed to calculate magnetic flux (pre-i, 52-57).
Conceptual teaching strategies & Representations		
4.1 What are your teaching procedures (and particular reasons for using these to engage with this idea)?	• (Nothing identified in CoRe) • Show videos and simulations that indicate changing magnetic fields (pre-i, 65-67).	• Show videos and simulations so that learners can see how things change. • Use a wooden apparatus representing a coil and magnets to explain magnetic flux with fingers representing magnetic field lines (pre-i, 25-27 & 45-47)
4.2 Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses)	• (Nothing identified in CoRe or pre-interview)	• Do extra exercises on this topic to first make sure whether learners understand or not. • Will make use of extra lessons to determine if learners understand the content or not.

5.6.1 Curricular Saliency

Sarah's first key idea of 'Magnetic fields' is a pre-concept taught in Grade 10 which forms part of learners' prior knowledge rather than a key idea in Faraday's law according to the expert CoRe. The second key idea of 'Magnetic flux' is a relevant key idea in Faraday's law that also appears in the expert CoRe. The sequence in which Sarah planned to introduce key ideas was as follows: Magnetic flux (with a revision of magnetic fields before flux is introduced), and then Faraday's law (pre-i, 7-8 & 10-12). The key idea of 'The phenomenon of induction' or the sub-ordinate idea of Lenz's law were not specifically referred to by Sarah in her CoRe or pre-interview.

Sarah did not select 'Faraday's law' or 'Induced emf' as separate key ideas but seemed to regard them as subordinate ideas to that of magnetic flux. For her response to prompt 2 (key idea B) of what she intended for learners to know about the key idea of 'Magnetic flux', she wrote that a "change in magnetic flux can induce [a] current (emf)". A similar response was also given in prompt 3 when she explained why it is important for learners to know magnetic flux. This indicates that she may have regarded Faraday's law as directly explaining why a current is induced in a conductor instead of seeing it as a result of the induced emf set up. The concept of the induced current was not explicitly discussed in her CoRe. Thus Lenz's law as a means to determine the direction of the induced current and Ohm's law to calculate its magnitude were not referred to by Sarah in her CoRe or pre-interview. Although Sarah did not identify 'Induced emf' as a key idea, she wrote for her key idea of 'Magnetic flux' that' "it is the basis for the working of motors and generators (Gr 12 work)" (prompt 4, key idea B) revealing that she is aware of the importance of Faraday's law and how it relates to subsequent topics. She also recognised the significance of magnetic flux as an important concept in Faraday's law. In her CoRe (prompt 3, key idea B) she wrote:

> Faraday's law is based on change in magnetic flux. If [learners] don't understand the term magnetic flux, they won't understand how it can create an emf.

She gave a description of magnetic flux as "the amount of magnetic field lines passing [perpendicular] to the area of [the] conductor" (prompt 2, key idea B), which is similar to the description of magnetic flux given in the expert CoRe. It was evident from her response for the same prompt that she deemed the various ways to cause a change in magnetic flux to be important. Sarah, however, only mentioned magnetic field strength as a specific factor that could cause a change in magnetic flux, excluding the area of the conductor and the angle as two other relevant factors. This could suggest that Sarah places a greater emphasis on practicing calculations for situations involving only a change in magnetic field strength with her learners.

Sarah identified few relevant keys ideas in the topic of Faraday's law. Crucial key ideas were seen as subordinate ideas while other key ideas selected were prior knowledge of learners. She revealed knowledge of subsequent topics such as Motors and Generators that relate to Faraday's law, but did not suggest that she was aware of these topics' interrelatedness with the concepts of alternating current or Lenz's law. When compared to the TSPCK rubric, Sarah revealed Basic (2) knowledge of *curricular saliency*.

5.6.2 What is Difficult to Teach?

The expert CoRe highlights learners' limited ability to visualise vectors such as magnetic fields and angles in three dimensions. This results in their inability to determine the angle between the magnetic field and the area vector. Sarah referred to this difficulty in her pre-interview, stating that learners struggle with determining the angle needed to calculate magnetic flux and relating the correct angle to the words such as 'parallel' and 'perpendicular'.

> [Learners] struggle to see that cosTHETA part. There's the angle between the magnetic field lines and the area to the coil. And they usually struggle to see that if it's perpendicular, that the normal and the magnetic field lines, the angle between them is zero. They usually say stuff like 90 or 180. (52-56)

Sarah also mentioned that "it is only a change in magnetic flux that can create a current" as a difficulty faced by her learners (prompt 5) for the key idea of 'Magnetic flux'. This is regarded as a major conceptual difficulty for learners as they tend to think that an emf will be induced by the mere existence of magnetic flux rather than when there is a change in flux through a conductor.

The reason why learners face the difficulty discussed above is due to the fact that field lines are imaginary. Sarah explained that "[learners] cannot see the magnetic field lines" (pre-i, 56-57). This leads to them having difficulty in visualising both magnetic flux and a change in flux.

Sarah's knowledge of this component of TSPCK was scored as Developing (3). She identified a major conceptual difficulty in that only a change in magnetic flux will result in the induction of an emf. She also identified mathematical difficulties learners face in determining the angle needed to calculate the magnetic flux and the cause for these difficulties. She stated that "because [magnetic field lines are] imaginary, some of [the learners] cannot see it as they cannot see that the field lines are going through the coil" (pre-i, 44-45).

5.6.3 Learners' Prior Knowledge and Misconceptions

Sarah saw magnetic fields as important prior knowledge in understanding electromagnetic induction. This led her to selecting it as a key idea for Faraday's law. She stated from prompt 2, key idea A of her CoRe that she intended for learners to know that magnetic field lines exist around a magnet and that they have a north and a south pole. She stated for the same key idea in prompt 3 that it is important for learners to understand that magnetic field lines are imaginary lines so that learners are able to understand how a coil can move through it. The expert CoRe identifies a misconception related to this idea in terms of learners' inability to realise that magnetic field lines are imaginary pictorial aids used to visualise magnetic fields while magnetic flux is an actual physical quantity. Sarah's decision to select magnetic fields and magnetic flux as key ideas suggests that she would place emphasis on ensuring learners are able to distinguish between the two concepts and in the process, address the related misconception.

Sarah identified one major misconception related to learners' prior knowledge but did not identify important pre-concepts from the topics of Energy and Electric Circuits. Based on the TSPCK rubric, her knowledge of this component has therefore been scored as Basic (2).

5.6.4 Representations

Sarah explained that she had used an apparatus consisting of wooden blocks and a loop which represented magnets and a coil to explain the concept of magnetic flux. In order to help learners visualise magnetic field lines passing through the loop, she would use her “fingers as the magnetic field lines so that they can see it’s actually the lines passing through [the coil]” (45-47). However, Sarah did not elaborate as to how this apparatus would be used to explain the different variables that affect magnetic flux, nor how she would use it to explain Faraday’s law.

Sarah expressed in her pre-interview (66-67) that she would also like to show learners simulations on the change in flux for them to understand it better. The simulations she described were meant to help learners visualise magnetic fields “so they can actually see a magnetic field is created [as revealed by a] compass [around a current-carrying conductor]. ...Or even turning the coil through a magnetic field to see how [the magnetic field] changes” (76-78). The first simulation referred to by Sarah relates to the broader topic of electromagnetism while the second one relates to Faraday’s law. Sarah stated in her pre-interview (65-73) that she planned to show these simulations only at a later stage but did not clarify when exactly. This would be ineffective as neither representation would support the teaching of the concept if they were shown to learners at a later stage.

In terms of representations of magnetic flux, Sarah was relying on only using simulations and demonstrations to explain the concept, stating in her pre-interview (27-28) that she did not draw any diagrams to support her teaching of magnetic flux as she was not good at drawing. This is detrimental to learners’ understanding of the concept as they will often need to interpret diagrams of magnetic fields and conducting loops in assessments in order to determine values such as angles. Diagrams which are two-dimensional in nature also need to be related to demonstrations for learners who struggle with visualising in three dimensions.

Representations allow learners to gain concrete visualisations of concepts that strongly aid understanding. Due to Sarah’s choice to rely only on demonstrations and not diagrams of magnetic flux, as well as her decision to show simulations of Faraday’s law during a later lesson, her knowledge of this component of TSPCK has been scored as Basic (2).

5.6.5 Conceptual Teaching Strategies

Sarah's CoRe and pre-interview suggested a lesson that was strongly focused on magnetic fields and magnetic flux as opposed to the phenomenon of induction and Faraday's law. This was evident both in the key ideas that she selected for Faraday's law as well as the representations that she had planned to use during her lessons. She referred to two specific representations, one of which was using a wooden apparatus to explain magnetic flux and the other, a simulation that would show learners the induction of magnetic fields around conductors which is to establish the relationship between electricity and magnetism. This is not directly related to Faraday's law which explains the induction of an emf and not the induction of magnetic fields around conductors. There was an absence of representations from Sarah's planning that would explain the phenomenon of electromagnetic induction. This had a clear impact on her conceptual teaching strategy. Factors that affect the magnitude of the induced emf, misconceptions regarding the induction of emf's, and subsequent topics that relate to Faraday's law such as alternating current were not referred to by Sarah. Her lack of representations of induction also suggest that her lesson would have a strong teacher-centred approach in which much of the content is taught in a lecture style with little input from learners. Many of her responses given in both her CoRe and her pre-interview dealt with the knowledge that she would teach with little indication of how she would involve learners in her lesson via questions posed to the class. She viewed her overall knowledge of Faraday's law as limited which could account for her lack of knowledge of effective teaching strategies. In her CoRe (prompt 7, key idea B), she wrote: "My limited knowledge influence[s] my teaching. I have to prepare a lot more [than other teachers] and watch videos".

Sarah wrote in her CoRe (prompt 6, key idea A): "Learners need to see where these topics are used in everyday life for them to understand it better. So it's always better to use real life examples". It was however unclear how Sarah planned to relate Faraday's law to learners' everyday lives as she did not expand on this idea.

When asked in her pre-interview how she would ascertain learners' understanding or confusion regarding the key ideas, Sarah stated that "you need to give [learners] a lot of exercises" (81-82). This strategy usually places emphasis on determining learners' understanding of content through their ability to do calculations. This does not give a true indication of their conceptual understanding as the process of identifying values and 'plugging' them into an equation does not reveal whether learners understand the underlying concepts or not.

Sarah's teaching strategy did not reveal evidence of how she would expose learners' misconceptions and difficulties through engagement with learners. Her lack of selection of representations for Faraday's law and her decision to use representations at a later stage after introducing Faraday's law indicates an underdeveloped knowledge in this component of TSPCK. Her knowledge of *conceptual teaching strategies* has thus been scored as Basic (2) when compared against the TSPCK rubric.

5.7 CASE STUDY 4 – LINDA (SCHOOL 2)

Linda holds an MSc degree in Physics as well as a Post Graduate Certificate in science education. She has been teaching Physical Sciences for 25 years and at the time of the study, she had been teaching Grade 11 Physical Sciences for 19 years. Her completed CoRe and full interview transcript can be found in Appendix III and IV respectively. Linda selected four key ideas in the topic of Faraday's law which are listed below in the order that she indicated she would introduce them:

- Key idea A: The magnetic effect of current
- Key idea B: Effect of magnetic field on current
- Key idea C: Magnetic flux
- Key idea D: Induced emf

Table 5.5: Reported PCK based on CoRe and pre-interview with Linda

Curricular saliency				
1.0 How were key ideas selected and sequenced?	• Key ideas will be introduced in the order from A to D (pre-i, 3).			
KEY IDEAS	**A: The magnetic effect of current**	**B: Effect of magnetic field on current**	**C: Magnetic flux**	**D: Induced emf**
1.1 What do you intend learners to learn about each key idea?	• The right hand rule. • A current-carrying conductor produces its own magnetic field (pre-i, 58). • The shape of the magnetic field produced by different shaped conductors (pre-i, 63-65).	• Magnetic field vs electric field. • A current-carrying conductor will experience a force in a magnetic field (pre-i, 34-35). • Fleming's left and right hand rule (pre-i, 102-103).	• Magnetic flux vs magnetic flux density. • A change in: the angle of the loop in a magnetic field, time, or rate of rotation causes changes in magnetic flux (pre-i, 145-147).	• Faraday's law in words and symbols.
1.2 Why is it important for learners to know this key idea?	• To understand the relationship between electricity and magnetism. This introduces key idea B. • To understand how the shape of the magnetic field around a solenoid is related to the shape of the field around a single loop	• Fleming's rules will assist learners to understand where the force that is exerted on a current-carrying conductor is coming from (pre-i, 108-110).	• Learners have to understand magnetic flux before they understand change in flux.	• Induction is needed to understand how motors and generators work in Grade 12.

	and a straight conductor (pre-i, 76-78)			
1.3 What else do you know about each key idea (that you do not intend learners to know yet)?	• Shape of field through the coil or solenoid.	• Fleming's left hand and right hand rules. • Lenz's law.	• Transformers operate on the principle of induction (pre-i, 133-134).	• (Nothing identified in CoRe or pre-interview)
1.4 Are there any other factors that influence you teaching of these ideas?	• Learners are not aware of the heating and magnetic effects of current (pre-i, 45-47).	• Learners do not realise that any form of moving charge such as a beam of protons, will experience a force in a magnetic field (pre-i, 112-114).	• Learners have to do calculations and must be able to interpret questions. • Learners do not know about the concept of magnetic flux (pre-i, 92-93 & 129).	• Question on the induced emf in exams are one-sided as they only focus on situations where flux is changing and not rate of rotation, number of loops or angle of the loop in the magnetic field leading to learners not coping if faced with a different factor changing (pre-i, 150-155).
Learners' prior knowledge and misconceptions				
2.1 What is your knowledge about the learners' thinking that influences your teaching of these ideas?	• Learners have very little background about these ideas. Magnetism and electricity have been treated as two separate fields up till now. • Learners are not aware of the effects of current such	• (Nothing identified in CoRe or pre-interview)	• Learners cannot cope with all the factors that can lead to a change in magnetic flux (pre-i, 147-150). • Some concepts taught and assessed in Grade 11 are applied again in Grade 12	• (Nothing identified in CoRe or pre-interview)

	as the heating and magnetic effects (pre-i, 45-46)		but not assessed (pre-i, 142-144).	
What is difficult to teach?				
3.1 What are the difficulties/limitations connected with the teaching of this idea?	• Abstract ideas. • Phenomena that are not visible to learners. • Need to find visual / 3D representation of ideas.	• (Nothing identified in CoRe or pre-interview)	• Learners are confused between the similar terms of magnetic flux and magnetic flux density (pre-i, 9-10).	• (Nothing identified in CoRe or pre-interview)
Conceptual teaching strategies & Representations				
4.1 What are your teaching procedures (and particular reasons for using these to engage with this idea)?	• (Nothing identified in CoRe or pre-interview)	• YouTube video of effect of magnetic field on a conductor. If learners don't see it, they will not understand. Difficult to reproduce in class.	• I use diagrams to build up the idea of magnetic flux and change in flux.	• Demonstrate with a torch that uses induction.
4.2 Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses)	• (Nothing identified in CoRe or pre-interview)	• (Nothing identified in CoRe or pre-interview)	• (Nothing in CoRe or pre-interview)	• Learners' ability to solve problems independently.

5.7.1 Curricular Saliency

Linda's key ideas of 'Magnetic flux' and 'Induced emf' are the same as those in the expert CoRe. Key idea A of 'The magnetic effect of current' is a concept that learners are introduced to at the beginning of the topic of Electromagnetism in Grade 11 but is not a key idea in Faraday's law according to the expert CoRe. Key idea B of the 'Effect of magnetic field on current' is related to the Grade 12 topic of Electrodynamics and is not considered a key idea for Faraday's law in Grade 11. It was evident from her CoRe (prompt 3) that she had selected key ideas A and B to establish the foundation of the relationship between electricity and magnetism, explaining in her pre-interview that these key ideas were important as this relationship was seldom understood by learners.

> [Faraday's law is] not actually the current creating a magnetic effect but the conductor reacting to a magnetic field. So the two concepts are intertwined but the children do not see the difference between the two clearly. (48-51)

She also felt that the ordering of content and concepts as it currently stood in the curriculum document did not allow for conceptual understanding, thus she presented an alternative sequence.

> In Grade 10 [learners] do the shape around a bar magnet and that's about that with similar poles or opposite poles or a single bar magnet. And all of a sudden you introduce the concept of magnetic flux. But I think they should start calculating magnetic field strength earlier. …So maybe you can start doing calculations about magnetic flux earlier when you introduce the concept of the magnetic field lines. (pre-i, 87-95)

Although she had planned to teach magnetic flux before Faraday's law, she felt that the concept should rather be taught in Grade 10. She recognised the importance of Faraday's law in topics that learners will study in Grade 12 as well as in post-school studies. She stated that:

> [Learners] do Faraday's law of electromagnetic induction now … because next year they are just studying motors and generators. (pre-i, 19-21)

> The thing that [learners] will never know, transformers operate on the principle of induction. (pre-i, 133-134)

Linda recognised that Lenz's law relates to electromagnetic induction but saw it as a separate idea unrelated to Faraday's law and thus not necessary to be taught during a lesson on it (pre-i, 17-19). She was aware that Lenz's law is used to determine the direction of the induced current and that the law is based on the idea that the magnetic induction is being opposed. However, she did not mention the significance of the induced field or why it sets up in a direction so as to oppose the change in flux.

Linda's key ideas A and B are considered pre-concepts rather than important ideas in Faraday's law. Although she selected the relevant key ideas of C and D, her TSPCK did not suggest that she would introduce the phenomenon of induction as an important idea. Her sequencing was logical and would allow for conceptual understanding due to the fact that she indicated she would introduce magnetic flux before Faraday's law. She recognised the importance of Faraday's law and its relationship with topics that learners study in Grade 12. However, Linda did not demonstrate knowledge of important conceptual ideas relating to Lenz's law. Linda's knowledge of *curricular saliency* has been scored as Basic (2).

5.7.2 What is Difficult to Teach?

The shape of the induced magnetic field produced by different conductors as well as the factors that influence the magnitude of the induced emf were regarded by Linda as difficulties in the teaching of Faraday's law. This was not attributed to learners' difficulty in understanding these concepts but rather to the limited time allocated to teaching the topic of Faraday's law in the curriculum.

> [Learners] have to understand what the magnetic field looks like around a straight conductor, around a loop, around a solenoid and those are all things neglected in the current syllabus. We don't have enough time to go into detail of each one of those. But I think it needs to be a progressive build up from [starting] simple. (pre-i, 64-68)
>
> The concepts are progressing too quickly from that to the very complicated and missing the steps in between. (pre-i, 70-71)

The insufficient time allocated to teaching Faraday's law is a general difficulty that does not account for the inherent difficulty in the underlying concepts in the topic.

Linda pointed out that the concepts of induction and magnetic flux were new to learners which added to the difficulty of the topic of Faraday's law (pre-i, 129). These difficulties may stem from the fact that the topics of Electricity and Magnetism have been treated as separate fields in previous grades. In her pre-interview, Linda stated:

> To me it feels like they don't know a thing. It's a very complicated [topic] which they don't even know the basics. So you try to get them to that complicated level without having any background on it. So it feels like everything I'm telling them is new to them. (124-127)

Another reason that Linda gave in her CoRe for Faraday's law being regarded as difficult is that it contains abstract concepts that are not visible to learners and thus require three-dimensional representations of ideas (prompt 5, key idea A). Learners struggle to visualise vectors in three dimensions. This particularly impacts their ability to determine the angle required to calculate flux. Linda's emphasis on using three-dimensional representations would aid in addressing this difficulty.

Although Linda identified teaching time as a difficulty, this is not regarded as unique to Faraday's law. She did identify major difficulties regarding the number of new concepts, specifically induction and magnetic flux, which learners are introduced to. She suggested that three-dimensional representations should be used to aid understanding of these concepts. Linda's knowledge of this component is scored as Developing (3).

5.7.3 Learners' Prior Knowledge and Misconceptions

Linda was aware that electricity and magnetism formed part of learners' prior knowledge. She had written in prompt 6 (key idea A) of her CoRe that learners have very little background knowledge regarding the topic of Electromagnetism and its concepts as the topics of Electricity and Magnetism had up until that point been treated as separate fields. She was of the belief that Fleming's left and right hand rules as well as the concept of the magnetic effect on current should be taught in Grade 11, forming part of learners' prior knowledge, as it would aid the conceptual understanding of Faraday's law. As mentioned earlier, these concepts are currently taught in Grade 12. Instead of identifying relevant pre-concepts in her pre-interview, Michelle discussed the need to emphasise and practically demonstrate the shape of magnetic fields around conductors (pre-i, 63-70).

Although Linda was aware that the topics of Electric Circuits and Magnetism taught in Grade 10 formed part of learners' prior knowledge for Faraday's law, she did not report any possible challenges that may hinder learners' understanding of new concepts. She instead felt that if key ideas A, B, and C had been taught well, learners would not struggle with the idea of induced emf (pre-i, 118-119).

Linda was asked in her pre-interview to describe typical learner misconceptions related to her key ideas. She answered that there were no particular misconceptions that she could identify but that learners rather had difficulties coping with various factors that could create a change in the magnetic flux.

Much of Linda's responses regarding prior knowledge revolved around what she believed should form part of learners' prior knowledge. Although she was cognisant that electricity and magnetism did form part of the learners' prior knowledge, exactly what pre-concepts from these topics were important for the understanding of Faraday's law were not discussed. Furthermore, misconceptions relating to these topics were not specified. Therefore, based on the TSPCK rubric, Linda's knowledge of this component has been scored as Basic (2).

5.7.4 Representations

Linda placed an emphasis on representations of Fleming's left and right hand rules. She planned to show learners a video of the magnetic effect of current so that:

> [learners] realise that if you have a current carrying conductor in a magnetic field, it will experience a force, so that they will understand there's a relationship between electricity or moving currents and magnetic fields. (pre-i, 34-37).

Fleming's rules, however, relate to motors and generators studied in Grade 12 and are not necessary for understanding Faraday's law or the relationship between current and magnetism. The RHR which learners need to know to determine the direction of the induced current is different to that of Fleming's RHR. Linda did not mention demonstrating the RHR used for determining the direction of the induced current.

For prompt 8, key idea C of her CoRe, Linda wrote: “I use various diagrams to build up the idea of magnetic flux and change in flux”. She explained in her pre-interview the type of diagrams that she would use and her purpose for using them:

> [I would use diagrams] where the loop or the coil or the twisted wire is illustrated and where the magnetic field is illustrated graphically. I will show them diagrams from the side, always a cross-section, because I hope that they will understand the concept of this invisible magnetic field that they can’t see. (161-164)

Linda’s use of diagrams was meant to help learners visualise magnetic fields. However, she did not provide more information about how they support the discussion of the concept of magnetic flux.

In her CoRe (key idea D, prompt 8), Linda wrote that she would use an induction torch to demonstrate induction. Although such a torch could be used to demonstrate the phenomenon of induction, it would not be effective in explaining Faraday’s law as learners would not be able to see the magnet inside moving through coils of wire.

Linda’s representations of magnetic flux and induction are relevant representations but she did not provide information about how she would use the representations to explain important concepts. She also did not mention important representations such as the RHR or representations to explain Faraday’s law. Her knowledge of *representations* has thus been scored as Basic (2) based on the TSPCK rubric.

5.7.5 Conceptual Teaching Strategies

Linda’s conceptual teaching strategy started with her focusing on learners’ understanding the concept of induction of magnetic fields around conductors and the effect of magnetic fields on them.

> So I think you should start with the effect of current which causes a magnetic field and then they have to realise that therefore it’s the inverse that the magnetic field will also have an effect on flowing current. (pre-i, 51-54)

She emphasised these two key ideas as she believed that learners often struggled to grasp the relationship between electricity and magnetism which hindered their understanding of Faraday’s law.

For prompt 9, key idea D of her CoRe, she wrote “Are they able to solve problems independently?” in response to the question of how she would ascertain learners’ understanding or confusion around her key ideas. This seemed to be a general answer in terms of all her key ideas for prompt 9 which may indicate a lack of effort to plan a conceptual teaching strategy that would allow her to track her learners’ understanding throughout her lesson. No indication was provided as to the kind of questions that Linda would pose to her learners in order to facilitate determining learners’ understanding of pre- or new concepts. Questions that learners solve independently are usually given to learners to complete at the end of teaching a topic and serve as a form of summative assessment. Exam and textbook questions on Faraday’s law also usually focus on calculations for which learners’ ability to solve such questions can provide a false image of their understanding of the underlying concepts.

Linda expressed that the limited time allocated to teaching the topic of electromagnetism in the curriculum document prevented her from explaining concepts in enough detail to ensure learners’ understanding thereof. However, she did not explain how she would take the limited teaching time into account in her conceptual teaching strategy to ensure the topic was taught as effectively as possible.

In her interview, Linda provided a teaching strategy that was based on an alternate ordering of concepts that she would like to see in the curriculum. She believed that concepts such as magnetic flux should be taught in Grade 10 while Fleming’s rules should be introduced in Grade 11 for conceptual understanding of the relationship between electricity and magnetism. This resulted in her revealing little knowledge about the conceptual teaching strategy she would employ based on the current curriculum and its ordering of concepts and content as it stood. For these reasons, her knowledge of this component of TSPCK was scored as Basic (2).

5.8 SUMMARY

This chapter began with a description of what constitutes exemplary knowledge within each component of TSPCK followed by a discussion of the process used to analyse and present the data. A summary of the teachers’ scores for each component of TSPCK based on the Reported PCK Rubric was then presented. For the teachers’ reported PCK, detailed analyses of the teachers’ CoRes and pre-interviews in terms of the five components of PCK were presented beginning with a summary of the teachers' reported PCK. The next chapter presents an analysis of the teachers' lesson observation and post-interviews.

CHAPTER SIX: LESSON PRESENTATIONS ON FARADAY'S LAW

6.1 INTRODUCTION

This chapter provides an analysis of the observations of the teachers' lessons and post-interviews (see Appendix V). The analysis provides insights to answer the third sub-question: How do the teachers' presentation of lessons on Faraday's law align to the curriculum, or deviate from it? An overview of how the data was analysed is provided in the next section. Each teacher's lesson is then discussed separately, beginning with a vignette for an overall view of the sequence and content of the lesson. This is followed by an analysis of the lesson, particularly focusing on the alignment or deviation with the information provided in the curriculum through the components of TSPCK.

6.2 OVERVIEW OF THE ANALYSIS OF THE DATA

This section provides an overview of the analysis of the teachers' lessons on Faraday's law in relation to the curriculum. The lessons were analysed through the components of TSPCK by looking for particular aspects that relate to these components. A discussion of these aspects follows.

6.2.1 Curricular Saliency

In terms of the *curricular saliency*, the focus of the analysis will be on: (i) the concepts related to Faraday's law that are prescribed in the curriculum and whether these were all taught by the teacher; (ii) the sequence in which the concepts/aspects were discussed; and (iii) the importance of the concepts and their interrelatedness within the curriculum.

6.2.2 What is Difficult to Teach?

Generally, the curriculum does not specify concepts that are difficult for learners. However, it provides 'Guidelines for teachers' for various reasons including the teaching of concepts that are documented as difficult in the literature. In the literature, difficulties in each of the concepts that are prescribed in the curriculum on Faraday's law are documented. These are listed in the expert CoRe (Appendix I). The analysis in terms of this component will thus focus on how teachers engaged with the concepts prescribed in the curriculum, looking particularly into their areas of difficulty.

6.2.3 Learners' Prior Knowledge and Misconceptions

The curriculum does not specify the prior knowledge required for any specific topic. As such, I have looked through the curriculum as a whole, including previous grades, to elicit topics and concepts that are scheduled earlier than Faraday's law in the curriculum. As indicated in Chapter Five, I regarded the earlier topics and concepts as prior knowledge for Faraday's law. These are: Magnetism, Electric Circuits, and Energy. The magnetic fields of current-carrying conductors which is taught to learners before Faraday's law in Grade 11 is also considered as prior knowledge as learners require an understanding of this in order to apply the RHR to the induced current. The analysis in terms of this component will thus look at the prior knowledge that teachers refer to and how they engage with it, particularly in terms of gaps and misconceptions.

6.2.4 Representations

The curriculum lists the following apparatus that teachers should use to perform a practical demonstration of Faraday's law: solenoid, bar magnet, galvanometer, connecting wires. The curriculum also states that words and pictures should be used to explain what happens when a bar magnet is pushed into or pulled out of a solenoid. The last representation suggested by the curriculum is the RHR. A description of what the thumb and fingers of the right hand represent is discussed in the section of Faraday's law in the curriculum. The analysis in terms of this component will thus look at the teachers' use of representations in relation to the recommendation made in the curriculum.

6.2.5 Conceptual Teaching Strategies

The curriculum does not recommend teaching strategies apart from guiding teachers on the concepts, practical work, and apparatus that should be included in their lessons. Conceptual teaching strategies require teachers to integrate their knowledge of the four previous components in order to create an effective teaching strategy. As such, the analysis of the lessons in terms of teaching strategies will focus on the preceding components of PCK relative to the curriculum. For example, the practical demonstration of Faraday's law as well as the curriculum noting that words and pictures should be used to explain what is observed, is regarded as forming part of an effective teaching strategy. The curriculum also notes that teachers should stress that electromagnetic induction is based on the idea of rate of change of *flux*, indicating the importance of this idea when teaching the concept.

6.3 CASE STUDY 1: MICHELLE

Michelle had begun teaching the topic of electromagnetism on the day before I observed her lesson on Faraday's law. She stated in her pre-interview (3-8) that she had taught about magnetic fields around conductors, explained the concept of magnetic flux and had shown how to calculate a change in flux in her previous lesson. However, she repeated teaching flux in the lesson I observed. A vignette of this lesson is given below.

> Michelle began her lesson by revising the magnetic fields of three differently shaped conductors that learners had been introduced to in their previous lesson as well as the properties of magnetic field lines. She defined magnetic flux as the number of magnetic field lines moving through the area of the conductor. She reminded learners that there are three different cases of magnetic flux in terms of the conducting loop being oriented either parallel, perpendicular, or at an angle to the magnetic field. Michelle went on to introduce the class to the idea of rate of change of magnetic flux. This was done by writing the expressions of $\Delta\emptyset = \emptyset_f - \emptyset_i$ and $\frac{\Delta\emptyset}{\Delta t}$ on the projector and explaining that 'a change in' meant a final value minus an initial value while rate meant time was involved. She used these expressions to explain to learners that the reason for learning about magnetic flux was to understand Faraday's law for which the expression of $\frac{\Delta\emptyset}{\Delta t}$ was part of the formula for calculating it. She then read out from the notes she had typed for her learners that a change in magnetic field around a conductor induces an emf and an electric current. The formal definition for Faraday's law was then stated after which she proceeded to write the equation for the law on the projector, asking learners to identify the variables that they saw in the equation. She asked the class why the formula had a negative in it. A learner who seemed to have read ahead replied that the magnetic field and emf oppose each other. Michelle responded by stating that "there is something resisting something else". Once learners had copied the equation for Faraday's law into their notes, Michelle continued to read out from the notes the variables that influence the magnitude of the induced emf. Learners were referred to a page in

their textbooks which showed a worked calculation of Faraday's law. Michelle worked through the example, explaining that it was important to write out the variables from the question that were needed for the calculation. After this very brief introduction to Faraday's law and a practice calculation, Michelle pointed out that the direction of the induced current also needed to be "calculated" which is where Lenz's law came in. She stated Lenz's law and explained that the magnetic field generated by the conductor will always oppose the change in magnetic flux as the magnetic field generated is trying to keep the magnetic flux constant. Michelle then spent the majority of the lesson on drawing diagrams on the overhead projector of magnets entering or exiting solenoids with different poles facing the solenoid. Throughout explaining Lenz's law with her diagrams, learners were asked to hold their right hand in the air and to practice the RHR with her in order to determine the direction of the induced currents in the diagrams. Michelle used the last few minutes of her lesson to complete the first question from a textbook exercise on Faraday's law.

Vignette: Michelle's lesson

6.3.1 Curricular Saliency

Michelle discussed the majority of the concepts that are prescribed for Faraday's law in the curriculum. She first introduced the key idea of 'Magnetic flux' in a previous lesson (pre-i, 6-8) and in the following lesson that I observed lesson, she introduced Faraday's law. Michelle did not perform a demonstration that allowed learners to observe a current induced in a conductor. Instead, she used a bottle and a pen to discuss the direction of the induced current rather than the phenomenon of induction. Thus, Michelle was regarded as not introducing 'The phenomenon of induction' as a key idea which is included in the expert CoRe.

Michelle's sequencing of concepts did not follow that implied in the curriculum. She introduced magnetic flux first, before stating Faraday's law, in agreement with her pre-interview (6-7). This is different from the curriculum which could be interpreted as suggesting that Faraday's law is the first thing teachers should state. She explained her reason for introducing magnetic flux before Faraday's law, stating:

> The whole concept goes around magnetic flux. So first maybe just introduce [learners] to magnetic flux and maybe link Faraday's law to magnetic flux so they understand it better and then do the right hand rule. (57-59)

The concept of Lenz's law is discussed in the curriculum but it is not mentioned by name. Michelle indicated on two separate occasions in her post-interview that she taught Lenz's law because it was discussed in the Grade 11 textbook that she had used to plan her lesson.

> I chose to discuss Lenz's law because] it was in the … what was that book's name? That red and white book. (211-212)

> The other textbook focused on Faraday's law and then they did immediately Lenz's Law afterwards and they asked combined questions at the back of the book. That's why I did Lenz's Law as well. (224-247)

Michelle provided a shallow explanation for Lenz's law stating that the magnetic field generated is trying to keep the magnetic flux constant. She had seen in an internet search that this related to energy conservation principles but did not seem to understand it entirely. Had she understood it or explained it in more detail, learners would likely have had a better conceptual understanding of the induced current which is not conceptually discussed in the curriculum.

The content included in the two textbooks that Michelle used to plan her lessons on Faraday's law influenced her teaching of the topic, particularly with regard to what content to teach. This follows after she confessed that she did not use the curriculum document to prepare for her lessons in the post-interview (10-12). Calculating the induced current was also taught because Michelle had seen it discussed in textbooks (post-i, 238-247).

6.3.2 What is Difficult to Teach?

Much of Michelle's lesson was spent doing examples to practice the RHR. Her examples included all possible scenarios of magnets entering or exiting solenoids. The curriculum is regarded as alluding to the fact that learners have difficulty applying the RHR. Michelle's statement below from her post-interview indicated that she was aware that learners struggle to apply the RHR to the induced current and its magnetic field.

> [Learners] struggle with getting the direction of the induced current because they usually face their thumb in the north direction of the bar magnet and not in the induced north. So then they get the induced current wrong as well. (368-370)

Rather than directly addressing this difficulty in class and stressing which magnetic field the thumb needs to point in the direction of, Michelle performed a number of examples in hopes that learners would come to remember which magnetic field to apply the rule to.

Although magnetic flux is a new concept to learners, the curriculum does not allude to any difficulties regarding it. Michelle noticed in her previous lesson that learners had difficulty with regard to magnetic flux, particularly with interpreting the orientation of a conductor and the angle used to calculate flux (pre-i, 146-150). She addressed this difficulty by drawing three diagrams on the overhead projector of magnetic fields passing parallel, perpendicular, and at an angle through the conductors and explaining the angle.

Michelle addressed one difficulty which related to magnetic flux which only became known to her while teaching, while a major difficulty regarding the RHR alluded to in the curriculum was not directly addressed. Her statement: “I handed them extra activities of previous exam papers and they were fine with it” (post-i, 86-87) suggests that she relied on class activities to uncover difficulties instead of actively addressing those that she was aware of during her teaching.

6.3.3 Learners’ Prior Knowledge and Misconceptions

Michelle had identified Magnetism and Electrostatics as prior knowledge in her CoRe. During her recap of magnetic flux in her lesson on Faraday’s law, she only drew on learners’ prior knowledge of magnetism by revising properties of magnetic field lines. In her post-interview, she described concepts from the topic of Magnetism that she regarded as important and should be taught to learners before they are introduced to Faraday’s law. She stated:

> The basic magnetic force, so say north to north, south to north, that around a bar magnet are magnetic field lines. Because there in Gr 10 they did a whole chapter on magnetic fields and how to draw them. ...I think they need to do that before they can change in magnetic field. (330-333)

It appeared that Michelle was referring to magnetic fields and how they are represented by field lines as well as what their shape is between like poles and opposite poles.

Michelle indicated that learners' knowledge of emf and "how electrons move through the circuit" influence the topic of Faraday's law and the way in which she teaches it (post-i, 20-21) but she did not revise the concepts of emf or current when she mentioned them in her lesson. Her own understanding of emf did not seem complete from comments in her post-interview (301-306):

> Researcher: If a learner asked you what EMF is, how would you explain it?
>
> Michelle: Electromotive force.
>
> Researcher: And if they asked you what does that mean?
>
> Michelle: Then I'll give them the definition that I can't remember now.

Concepts from the topic of Energy such as energy conversions and the law of conservation of energy which relate to electromagnetism, were also not mentioned in her lesson. These concepts are not explicitly mentioned in the section of Faraday's law in curriculum, unlike emf, current, or magnetic field.

Michelle was asked in her post-interview (362-366) if learners have any misconceptions regarding any of the concepts in Faraday's law. Instead of identifying misconceptions, she discussed two difficulties which related to describing the orientation of a conductor in a magnetic field, and the RHR. She also did not address any misconceptions in her lesson on Faraday's law.

6.3.4 Representations

The curriculum states that Faraday's law must be demonstrated for learners, providing a list of apparatus that can be used to perform this demonstration. Michelle used a bottle, pencil, and fingers instead to represent a solenoid, a magnet, and directions of induced current respectively. Her demonstration focused predominantly on the induced current and showing learners how to apply the RHR to determine its direction. Emphasis was not placed on how the current was induced or that an emf was generated. When asked if she explained what happens when a bar magnet is pushed into or pulled out of a solenoid, as expected by the curriculum, she replied:

> I used a bottle and then showed with a pen, the magnet is moving into the bottle and out of the bottle. And then in which way is the current going to move using my fingers. (post-i, 41-44)

Learners were thus not properly given the opportunity to observe the phenomenon of induction. Without such a demonstration or investigation by learners themselves, Faraday's law would remain an abstract concept to learners. She realised after teaching Faraday's law, the importance of representations, stating:

> Next year I will make use of more practical examples to make it easy for them to understand. Maybe just to show them an example on, or a simulation where [induction] happens and then start explaining so that it's not that farfetched for them. (post-i, 390-392)

> So the same as the CAPS document, you use the solenoid and the bar magnet and the galvanometer and connecting wires and show them how it looks. And then maybe just make use of the solenoid and bar magnet instead of a bottle and pen. (post-i, 271-273)

Her comments indicated that she would choose to use the apparatus so that learners know how they look, rather than being aware of what they could be used to show that a bottle and a pencil cannot. The curriculum does not explain how the listed apparatus should be put together or used to perform a demonstration of Faraday's law. Representations not suggested in the curriculum, but which Michelle showed learners, were that of diagrams to explain magnetic flux and Lenz's law (Figure 6.1).

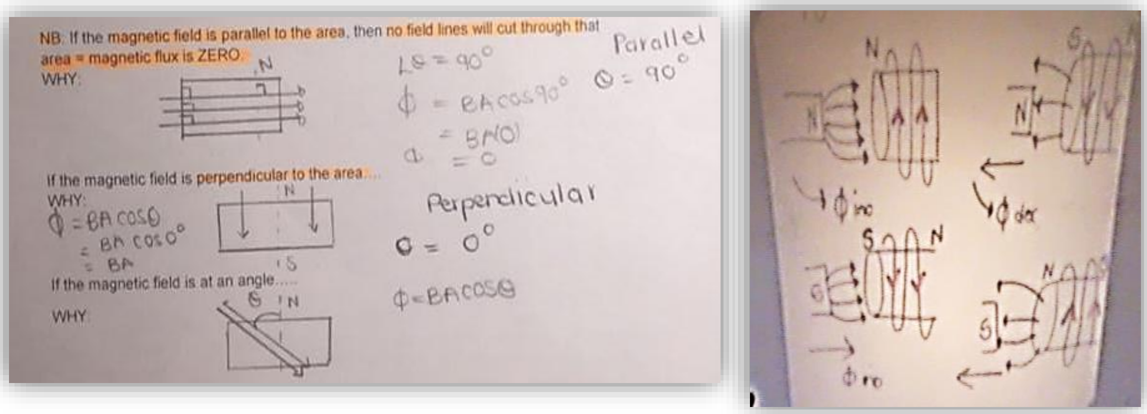


Figure 6.1: Notes taken down by learners explaining magnetic flux (left) and diagrams used by Michelle to explain Lenz's law and the RHR (right)

Michelle used the diagrams (see left in Figure 6.1) to explain three different cases relating to the orientation of a conductor in a magnetic field. Her diagrams are not clear as to whether the dotted line used to represent the normal vector (N) lies perpendicular or parallel to the surface area of the coil. This relates to learners' ability to visualise vectors in three dimensions for which these diagrams would further confuse learners. The diagrams in Figure 6.1 (right) were used to explain Lenz's law and the RHR. The pictures on the left indicate the magnetic field of the approaching bar magnet while the pictures on the right show the direction of the induced field. A better conceptual approach would have been for Michelle to combine these diagrams for learners to observe how the fields repel each other in order to oppose the change in flux.

6.3.5 Conceptual Teaching Strategies

Michelle chose to introduce the concept of magnetic flux first, rather than state Faraday's law as indicated in the curriculum. This sequencing is regarded by the expert CoRe as more effective, allowing for better conceptual understanding. Of the two demonstrations mentioned in the CoRe, Michelle only demonstrated the RHR. The biggest shortfall of Michelle's lesson was the fact that she did not demonstrate or organise a practical activity of the phenomenon of induction, thus she did not use the apparatus recommended in the curriculum. Her demonstrations, rather, focused on the induced current and determining the direction of the current with the RHR which relates to Lenz's law, not Faraday's law. She did, however, use diagrams to explain magnetic flux and the angle required to calculate it which are not mentioned in the curriculum.

Learner involvement was limited in Michelle's lesson. She asked some questions to elicit learners' prior knowledge of magnetic field lines and the reason for the presence of the negative in front of the formula for Faraday's law. However, she did not ask questions during demonstrations to gauge learners' understanding. She left exercises for practice until the end of the lesson instead of after finishing teaching a particular key idea, suggesting that she did not sufficiently plan a conceptual teaching strategy for eliciting learners' understanding. This would have helped Michelle pick up if learners had difficulties understanding any of the concepts.

The curriculum states that teachers must stress that Faraday's law relates the induced emf to the rate of change of *flux*. Michelle stated this to learners and demonstrated an understanding of the importance of this relationship by using it as a means to relate magnetic flux (which she introduced first) to Faraday's law.

In terms of content relating to conceptual teaching strategies in the curriculum, Michelle stressed that Faraday's law relates induced emf to the rate of change of *flux* as well as demonstrated the RHR for learners. She however, approached Faraday's law from a theoretical perspective, focusing on the formula, promoting an algorithmic approach to solving calculations involving induced emf. No demonstration of induction was performed to provide learners with a concrete idea of the concept of induction. Her teaching strategy placed little focus on learner involvement or using questions to determine their understanding.

6.4 CASE STUDY 2: TEBOGO

Tebogo finished explaining the induction of magnetic fields by currents in a previous lesson. In the following lesson which I observed, Tebogo introduced Faraday's law by discussing the phenomenon of induction. A vignette of this lesson is presented below.

> Tebogo began with a video demonstrating the phenomenon of induction and explained to the class what the galvanometer seen in the video is used for. He stated that learners were aware that if the ends of a conductor were connected to a battery, a current would flow through it because a battery sets up an emf across the ends of the conductor. He asked learners to observe when the needle of the galvanometer would move in the video. Tebogo explained that an emf is induced across the solenoid only if there is relative movement between the magnet and the solenoid which meant either the magnet could be moved back and forth or the solenoid moved. He stated that the induction of an emf by moving a magnet and a conductor relative to each other is explained by Faraday's law. He stated Faraday's law and explained that it describes what is required for an emf to be induced in a conductor. Returning to the video, he drew learners' attention to the needle that deflected in different directions. He explained that the current would change directions because it set up its own magnetic field in such a way as to oppose the change in magnetic field occurring through the solenoid. He reminded learners that they had already been taught that whenever a current flows in a conductor, it induces its own magnetic field and that in this case, the magnetic field induced by the current is always set up in such a way as to oppose the change in the magnetic field of the magnet passing through the loop. Tebogo explained that a version of the RHR is used to find the direction of the

current induced in the conductor. He applied the RHR to examples he drew on the board of magnets entering solenoids. He indicated that the thumb must point in the direction of the magnetic field generated by the current in the solenoid, which is opposing the change in field, and not in the direction of the field around the bar magnet. He gave learners two more examples for homework to practice applying the RHR. Tebogo wrote the equation for Faraday's law on the board and stated that the law refers to magnetic flux which has to do with the magnetic field of the magnet that is passing through the area encompassed by the solenoid. He drew a diagram of a magnet and field lines on the board and explained that in order to determine the emf induced in a solenoid, learners would need to calculate the amount of magnetic field passing through the area of a solenoid or any loop of wire and that this is known as the magnetic flux. The more field lines that pass through the area of a conductor, the larger the magnetic flux, and the fewer the field lines, the less the magnetic flux. He wrote the formula to calculate magnetic flux on the board and explained what each symbol represented and its unit and stated a formal definition of magnetic flux. He showed learners using a drawing what the relationship between the strength of a magnet, number of field lines, and magnetic flux is. Tebogo stated that it was also important to look at the angle in which the field lines passed through the coil as magnetic flux only takes into account the amount of magnetic field that pass perpendicularly through the cross-sectional area of the surface of the conductor. Using a piece of paper and a pen to represent the surface area of a conductor and field lines respectively, he explained the concept of a normal line and how it is used to calculate the amount of magnetic flux. The words used to describe the orientation of a conductor within a magnetic field were also related to the angle that formed between the normal line and the field and in which case flux would be a maximum or minimum. He drew a diagram of a loop with field lines passing through it and explained how the perpendicular component of the magnetic field could be calculated using the cosine trigonometric function. The lesson ended and Tebogo picked up the following day by returning to the demonstration of the pen through the paper and showed learners how the angle would affect the value of the flux. Before moving on, he recapped how the magnetic field strength, area of a conductor, and orientation of the loop could influence the magnitude of the magnetic flux. He returned to the video shown at the beginning of the lesson and explained that when the bar magnet was held stationary, a certain amount of magnetic field was passing through the loop which is the magnetic flux of the loop. However the presence of magnetic flux isn't enough to induce an emf in the conductor. He explained that when the magnet was moved in and out of the loop, the magnetic flux was constantly changing and that it is a change in flux that is needed to induce an emf. The change in flux is achieved by moving the magnet through the loop but that the magnet could also be held stationary and the loop moved or turned which would change the magnetic flux as well. Tebogo related induction to how electricity is produced by Eskom. He pointed to the $\Delta\Phi$ in Faraday's equation and stated that learners can see that a change in flux is required to induce an emf. He stated that a change in flux could occur due to a change in the magnetic field strength, area of a conductor, or orientation of the conductor in a magnetic field. He played the video once more and explained that if the magnet were to be moved through the coil faster which meant in a shorter amount of time, the change in the flux would occur quicker and would also increase the induced emf. He stated that how fast the flux is changed is referred to as the rate of change of flux and is the reason that a change in time also appears in the formula. This meant that a shorter time resulted in a greater induced emf whereas a longer time resulted in a smaller induced emf. Tebogo explained the difference between a loop and a solenoid and that the number of windings in the conductor relates to the *N* in the formula as it influences the magnitude of the induced emf. He also explained that a negative appears in Faraday's equation because the induced current sets up its own magnetic field which always opposes the change in flux through the conductor. He reminded learners that this idea was used when they applied the RHR to determine the direction of the induced current in a solenoid. Tebogo started on an example question from his notes which required learners to calculate change in flux and induced emf. He then gave learners the rest of the period to complete an activity from their notes.

Vignette: Tebogo's lesson

6.4.1 Curricular Saliency

Tebogo taught all the concepts prescribed in the curriculum but his lesson also included the key idea of 'The phenomenon of induction' present in the expert CoRe but not in the curriculum. He, however, introduced Faraday's law before the concept of magnetic flux which is regarded as less conceptually effective in the expert CoRe. Tebogo chose this sequencing as he felt that it was a means to introduce the need for the concept of magnetic flux and how it relates to Faraday's law.

Tebogo was aware that Lenz's law is not referred to by name in the curriculum but the idea that a change in flux is resisted by a solenoid is discussed in the curriculum. He knew that this idea and thus Lenz's law relate to the negative in the formula for Faraday's law and the RHR which are shown to learners (post-i, 202-203 & 206-209) but did not indicate how the direction of the induced field relates to energy principles.

In his post-interview (122-123), Tebogo explained that he started with a demonstration of electromagnetic induction as:

> Faraday's law only explains what we see. It is not induction itself. Learners must see what is happening and then you try explain it.

The concept of magnetic flux was only introduced after Tebogo discussed Faraday's law. Although the expert CoRe suggests introducing magnetic flux before Faraday's law and its equation, Tebogo regarded this as a more effective sequencing of key ideas as he wanted learners to be aware of the variables which influence the induced emf. He stated in his post-interview (128-129) that:

> I want [learners] to know that this is the sub-topic that we are going to do. This is the formula. The formula has these variables. One of them is the flux.

Tebogo discussed in class how Faraday's law relates to electricity generation, explaining in his post-interview (37-38) that "the core part of what happens with electricity is in the generators and electromagnetism". Practical applications and related topics in Grade 12 are not mentioned in the section of Faraday's law in the curriculum.

6.4.2 What is Difficult to Teach?

While teaching the RHR, Tebogo pointed out to learners that their thumb has to point in the direction of the magnetic field induced by the current when applying the rule, clarifying a difficulty noted in the expert CoRe. He also raised the fact that learners often become confused as to which version of the RHR to apply to solenoids as the fingers do not represent the same variables in different versions (post-i, 72-78). The curriculum does not acknowledge or differentiate between versions of the RHR even though application of the RHR as expected by the curriculum requires different versions in different scenarios.

Tebogo mentioned another learner difficulty. He explained that learners tend to confuse the concept of magnetic field and magnetic flux as they are unable to distinguish between the two (post-i, 139-141) although he did not address this difficulty during his lesson. No difficulties regarding the concept of magnetic flux, however, are alluded to in the curriculum.

6.4.3 Learners' Prior Knowledge and Misconceptions

Tebogo discussed concepts from the topic of Magnetism during his lesson but did not specifically elicit learners' prior knowledge about these topics in order to determine their understanding of them. He identified Magnetism as influencing his teaching of Faraday's law (post-i, 32) stating that learners need to understand the concept of north and south poles in order to apply the RHR for determining the direction of the induced current (91-92).

Tebogo discussed the concept of emf in his lesson and reminded learners that it is a type of potential difference. He also referred learners back to their understanding of what is required to create a current in a circuit, explaining that a battery connected to a conductor would cause a current to flow through it as an emf is generated across the ends of the conductor. He used this as a means to explain how a current was generated via induction in which a battery is not present. Tebogo identified the topic of Electric Circuits, and in particular, Ohm's law as necessary prior knowledge for the study of Faraday's law (post-i, 89-90). He indicated that this prior knowledge is important for learners to be able to recognise that a solenoid connected to a galvanometer constitutes a circuit (89-91). An exercise that he created for learners also showed that he was aware that learners would need to apply Ohm's law in order to calculate the magnitude of the induced current in a conductor. Current and emf are mentioned in the section of Faraday's law in the curriculum but Ohm's law and related calculations are not.

While discussing the video of induction, Tebogo pointed out that for an emf to be induced in the solenoid, there needed to be relative motion between a magnet and solenoid. He further explained that this meant that either the magnet or the solenoid had to be moved while the other is stationary. Tebogo explained in his post-interview that the concept of relative motion is important prior knowledge for the understanding of Faraday's law (96-94) but that it is no longer a topic that is taught to learners before Faraday's law as it was in the past. He addressed a misconception related to relativity and induction when he explained to learners that either a magnet or a solenoid needed to move in order to induce a current. He explained that "learners think that only if the magnet is moved will there be current but it doesn't matter which one moves. There must just be relative motion between the solenoid and the magnet" (post-i, 154-156). This misconception is not alluded to in the curriculum but does appear in the expert CoRe.

6.4.4 Representations

Tebogo showed a video demonstrating the phenomenon of induction and explained the use of the galvanometer. He had learners make important observations by drawing their attention to the needle of the galvanometer that deflected in different directions. Tebogo was cognisant of the importance of demonstrating induction, explaining that it allows learners to make important observations and as well as allowing them to link explanations in words to what they observed in a demonstration. This is in agreement with the curriculum's expectations that teachers perform a demonstration of Faraday's law and use words and pictures to explain what is observed.

> If I explain and I have a magnet and I have a coil and maybe I have a galvanometer, learners will see that if I move, something is happening. Then I have to explain why there is movement of the needle on the galvanometer. When I move the magnet relative to the coil or the coil relative to the magnet so that the learners sees. And then after showing them that, I can then explain 'What you saw there is a current that is being induced, or the voltage that is being induced.' Then they will be able to link what I am saying to the diagram. (post-i, 54-61)

Although the curriculum calls for a practical demonstration of Faraday's law and not a video, the apparatus listed in the curriculum were the same as those that appeared in the video used by Tebogo.

Although no representations for magnetic flux are suggested in the curriculum, Tebogo explained the concept using a pen, pencil, and paper to represent the normal line, magnetic field lines, and area of a conductor respectively (Figure 6.2). A demonstration with similar resources is also mentioned in the expert CoRe.

Figure 6.2: Tebogo and a student demonstrating magnetic flux

After showing the video demonstrating induction, Tebogo explained the RHR and drew diagrams on the board of magnets entering solenoids which he used as examples to find the direction of the induced current. The curriculum provides a description of how to apply the RHR as well as explains what the direction of the current in a solenoid will be if a north pole is either pushed into or pulled out of the solenoid. Tebogo explained the RHR similarly to how it is explained in the curriculum. He also addressed a difficulty regarding the rule when he explained how it is applied.

6.4.5 Conceptual Teaching Strategies

Tebogo began the topic of Faraday's law by showing learners a video of induction before introducing Faraday's law or magnetic flux. This allowed learners to observe the phenomenon of induction before discussing the physics behind it. Although the curriculum suggests a practical demonstration of Faraday's law, it does not state how the demonstration should be performed or what should be observed. Tebogo's teaching strategy included using questions to get learners to focus on certain details in the video such as when the needle of the galvanometer would deflect compared to when it would not, or to identify what learners believed was necessary for an emf to be induced in the conductor.

Similar to the sequencing suggested in the curriculum, Tebogo introduced Faraday's law before the concept of magnetic flux. In his post-interview (124-128), he indicated that by introducing Faraday's law and the formula first, he could show learners the variables, such as magnetic flux, in the formula that influence the induced emf, and discuss each of them one by one. The relationship between flux, particularly a change in flux, and induced emf was mentioned on a number of occasions throughout Tebogo's lesson. He was thus regarded as stressing that induced emf is based on the rate of change of flux as expected by the curriculum.

Demonstration and learner involvement was something that Tebogo ensured were part of his teaching strategy. Tebogo returned to the video of induction at various stages throughout his lesson, asking learners questions about what they observed. His questions were similar to those suggested in the expert CoRe as part of an effective conceptual teaching strategy. Learners were involved again when he explained magnetic flux by asking a learner to assist him in doing a demonstration with a pen, pencil, and piece of paper, asking questions while he performed the demonstration. For the RHR, he noted that it was important for learners to participate and perform the RHR with him. He stated: “I like seeing them doing those things using their hands. To me, it makes me see they are doing something” (post-i, 115-116).

Tebogo understood the importance of using representations in Faraday’s law and how they would allow learners to relate what they saw with the words and pictures used to explain induction. Explaining what he would say to learners when teaching Faraday’s law, he stated in his post-interview:

> ‘What you saw there is a current that is being induced, or the voltage that is being induced.’ Then they will be able to link what I am saying to the diagram. But if I’m standing here saying ‘Guys, it’s like a magnet’ ... without a picture, some of them have never seen a magnet in their life, some of them will switch off. I believe in showing them. (59-63)

He also indicated that a demonstration of induction is important in evoking learner interest. In the post-interview, he explained that from a young age, learners are kept engaged by “colours and … sound” but in school, the chalk and talk method does not keep learners interested (52-54).

6.5 CASE STUDY 3: SARAH

Sarah began discussing aspects of Faraday’s law a day before I observed her. In the previous lesson that I did not observe, Sarah introduced the idea of induced current. She then introduced the RHR followed by the concept of magnetic flux. A vignette of the following lesson that I observed is given below.

Sarah began her lesson by reminding learners that they had learned in their previous lesson that a current passing through a wire sets up a magnetic field which led to the conclusion that the opposite should also be possible whereby a magnetic field can induce a current. She explained the experiment originally performed by Faraday which demonstrated induction by drawing a diagram of the setup on the board. Sarah pointed out that a current was only induced in the setup when a change in magnetic field through the loop occurred. She stated that Faraday’s law was about a change in the amount of magnetic field through the conductor referred to as flux which will induce a current. She reminded her class of the previous lesson in which she taught that a stationary magnet inside a solenoid would not induce a current in the solenoid. Only if the magnet is moved into or out of the solenoid would there be an induced current. Sarah reminded learners that a simpler explanation of magnetic flux is

the number of field lines that pass perpendicularly through a loop. Using a wooden apparatus representing a coil, she recapped how the angle needed to calculate magnetic flux was determined as well as what the value of the cosine of that angle would be if the loop and the conductor were perpendicular or parallel to each other. She further explained how this related to the minimum and maximum magnetic flux passing through the loop. She stated that Faraday's law is based on the idea of a change in magnetic flux which could occur because of a magnet moving through a coil, a coil turning in a magnetic field or because a coil is moving through a magnetic field whose strength varied. This change induces an emf in the coil. She stated that learners knew the term 'emf' from Grade 10 and that it stood for maximum potential difference. She explained that if there is a change in the magnetic field due to a magnet and a coil moving relative to each other, there is an emf that is induced which delivers a current to a circuit. She stated that Faraday's law was the principle that learners would use to explain the operation of motors and generators that would be studied in Grade 12. She described how the setup in Faraday's experiment is similar to electricity generation for households. Using her wooden apparatus, Sarah demonstrated different ways in which a change in flux could be brought about and how these changes would affect the magnitude of the induced emf. She stated the formal definition of Faraday's law and wrote the mathematical relationship between induced emf and rate of change of flux on the board. She explained this relationship using the wooden coil which she rotated at different speeds. Sarah gave a practical example of Faraday's law by describing an interactive display learners may have seen at a science museum of a bicycle that, when ridden, powers a hairdryer or lightbulb. She explained that the faster a person peddled, the brighter the lightbulb would burn. She drew a graph on the board to represent the relationship between emf and change in flux and related the mathematical relationship to the shape of the graph. She explained that generators do not have a single coil but multiple coils as the more coils there are, the greater the induced emf will be. She brought these two relationships together by writing the equation for Faraday's law on the board and explained what each symbol in the equation represented and their respective unit. A learner asked why a negative appeared in the formula to which she admitted that she wasn't sure but that she had looked it up the previous evening and saw that it relates to Lenz's law. She explained that the negative compensated for the fact that the change in magnetic flux and the induced current have opposite directions. She explained that learners would come across Lenz's law in university which explained the presence of the negative in the formula. She explained that if learners were to do an experiment, they would see that the needle of a galvanometer would deflect in different directions due to the change in the direction of the induced current. Sarah wrote an expression on the board to calculate the change in flux. She described an example of a coil moving through a magnetic field of varying strength and explained that learners would have to calculate the change in the magnetic flux and then substitute the answer into Faraday's equation. She showed learners how they would write an equation to calculate the change in magnetic flux that was specifically brought about by a change in field strength. She then explained the effect of area size of a coil on the induced emf. She demonstrated this by covering half of the wooden coil's surface area and stating that a smaller area would lead to less magnetic flux passing through the coil. She described the relationship between the number of turns in a coil as well as the magnetic field strength and the induced emf. She started on a textbook exercise, writing on the board the information given in the question. The question stated that a coil is pulled perpendicularly out of a magnetic field. When explaining what the angle required to calculate the magnetic flux was, she told learners that it is zero as the surface of the coil is perpendicular to the magnetic field which led to an angle of zero degrees. The second part of the question asked for the current that passes through the coil if it is connected to a 25 Ohm resistor. Sarah asked learners how they would calculate it if they were given the value for voltage and resistance and they need to calculate the current. She stated that learners should think about circuits. A learner replied, “Ohm’s law”. The lesson ended after this.

Vignette: Sarah’s lesson

6.5.1 Curricular Saliency

The key ideas of ‘Magnetic flux’ and ‘Faraday’s law’ present in the curriculum were introduced in Sarah’s lessons. Instead of following the sequence implied in the curriculum, Sarah introduced magnetic flux before Faraday’s law. She recognised the importance of magnetic flux, stating in the post-interview that it is the most important concept referred to in the section of Faraday’s law in the curriculum because “magnetic flux plays such a big role in Faraday’s law. It’s because magnetic flux is changing that there’s an induced emf” (92-94). However, Sarah introduced magnetic flux before Faraday’s law because this was the sequencing in the textbook she used.

> I just followed the textbook. So I started with the whole magnetic field and then how sending a current through a wire can induce magnetic field, and then we went the other way round. Moving or changing magnetic field can induce a current. Then from there, I introduced magnetic flux. From magnetic flux, I introduced Faraday’s law. (post-i, 83-87)

Sarah indicated, however, that stating Faraday’s law before discussing magnetic flux, as sequenced in the curriculum, might help learners better understand what they will be learning about (post-i, 87-89). It appeared that she had not given much thought as to what sequencing would best allow for conceptual understanding, assuming the textbook’s sequencing was adequate.

The curriculum does not discuss Lenz’s law by name but the concept behind it is mentioned. Sarah had not planned to discuss Lenz’s law in her lesson but was forced to address it when a learner asked why a negative appeared in the formula for Faraday's law. Sarah admitted that she did not know why but that she had searched on google the previous evening for the reason. She was asked in her post-interview what she understood by the concept of Lenz's law. She replied:

> I don't know to be honest. No. I just know that on a video that I watched, they said that the negative of Faraday's law, that part where it's negative N delta phi over delta t, that negative is explained through Lenz's law. But I actually have no clue. (177-180)

The importance of the topic of Faraday's law and it relationship with future topics are not mentioned in the curriculum. It was evident that Sarah regarded this as important for learners to understand and was aware of how the topic relates to future topics learners will study. She stated in her post-interview that the topic of motors and generators influences the way in which she teaches Faraday's law (24-25), specifically pointing out that the RHR is used again in Grade 12 in this section of work (347-349).

6.5.2 What is Difficult to Teach?

Sarah stated to learners that the thumb of the right hand must point in the direction of the induced magnetic field's current (post-i, 61-62), thus addressing the difficulty implied in the curriculum regarding which magnetic field the RHR must be applied to.

During her revision of the concept of magnetic flux, Sarah addressed a difficulty regarding the angle required to calculate magnetic flux. This difficulty is not alluded to in the curriculum but Sarah explained in her post-interview that:

> [Learners] struggle with that angle, to understand that it's between the normal to the coil and the magnetic field lines. So they see it, if they say that the magnetic field lines are perpendicular to the coil, they tend to use cos90. (98-101)

Sarah only identified one relevant difficulty regarding learners' ability to determine the angle needed to calculate magnetic flux which relates to learners' ability to visualise in three dimensions. However, she did not identify the difficulty alluded to in the curriculum regarding the RHR in her post-interview.

6.5.3 Learners' Prior Knowledge and Misconceptions

It was evident that Sarah regarded learners' understanding of magnetism and in particular magnetic field lines taught in Grade 10 as important for the understanding of Faraday's law. She stated that she had revised magnetic field lines in her previous lesson to determine what learners still understood about them and filled in any gaps in their knowledge (post-i, 216-218).

Concepts from the topic of Electric Circuits were discussed during Sarah's lesson. She specifically reminded learners that they had come across the term 'emf' in Grade 10 and that it stands for "maximum potential difference". She also drew on learners' prior knowledge of Ohm's law while doing practice calculations with learners. Sarah stated that electric circuits are taught again in Grade 11 after Faraday's law and relates to it, as the concepts of current and emf are discussed again with learners (post-i, 20-21).

Sarah did not address misconceptions in her lesson. She was asked on two different occasions in her post-interview if there are any misconceptions that learners have in the topic of Faraday's law. On both occasions she spoke about the difficulty learners have in determining the angle required to calculate magnetic flux (239-241 & 326-328).

Certain concepts from the topic of Energy in Grade 10 are relevant to Faraday's law but were not identified by Sarah. She also did not address any misconceptions during her lessons or discuss any in her post-interview.

6.5.4 Representations

Sarah's first representation was a demonstration of the RHR which is included in the curriculum. She performed this demonstration in a previous lesson that I did not observe explaining to her class that a current could be induced in a conductor using a magnet (post-i, 54-55). This demonstration was not specifically used to discuss induction but rather the RHR. She used a magnet and a solenoid, apparatus listed in the curriculum, to describe the RHR performing a demonstration also similar to that described in the curriculum.

In the following lesson which I observed, Sarah explained Faraday's law by discussing an experiment that he conducted. A reproduction of the diagram that she drew on the board of this experiment is seen in Figure 6.3. The diagram of Faraday's experiment included the same apparatus that are listed in the curriculum to demonstrate Faraday's law. The experiment performed by Faraday did not involve a magnet being moved into or out of a solenoid. To compensate for this, Sarah also used a bar magnet and a solenoid to demonstrate to learners that a change in magnetic field through a conductor is achieved by moving a magnet relative to a conductor.

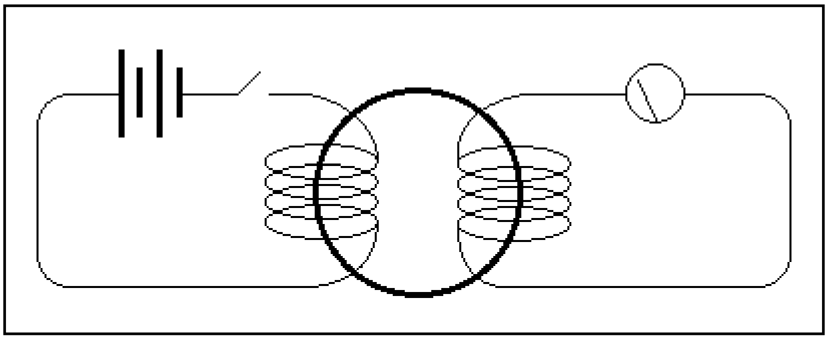


Figure 6.3: Diagram used to explain an experiment performed by Faraday

Although Sarah's diagram can be used to explain induction, it is problematic as it illustrates mutual induction which is beyond the scope of the curriculum and would need conceptual scaffolding before learners would be able to comprehend its connection to Faraday's law. The concept of a change in flux which underpins Faraday's law cannot be directly observed during mutual induction whereas if she had explained Faraday's law by demonstrating a magnet physically moving into or out of a solenoid, learners would be able to see that the amount of magnetic field passing through the coil is changing. The curriculum does not explain how the apparatus listed are to be used or what observations should be made during a demonstration of Faraday's law. Sarah was aware that it is important for learner to know what the various apparatus are, in particular the galvanometer (post-i, 302) as well as to observe when the needle of the galvanometer would deflect. However, she did not recognise how using a physical magnet and solenoid which she could move would be more effective for conceptual understanding. When asked how she would use the apparatus listed in the curriculum to perform a demonstration, she replied:

> To show that moving a bar magnet into and out of a solenoid can induce a current. So with that, they can see that the galvanometer is deflecting from the middle. And I think with that they can

> actually see that if you are pushing the magnet in, it goes to one side, and if you are pulling it out it goes to the other side. And if there's no movement, the galvanometer will be zero. (post-i, 380-384)

The curriculum provides an equation to calculate magnetic flux but does not suggest representations which can be used to explain the concept. Sarah, however, used the wooden apparatus of a coil to explain how a change in different variables such as field strength or orientation of a conductor could bring about a change in magnetic flux. These representations allow learners to see three-dimensionally conductors and the changes that would bring about a change in flux.

6.5.5 Conceptual Teaching Strategies

Sarah's sequencing of key ideas followed a conceptual approach similar to that suggested in the expert CoRe in which magnetic flux is introduced before Faraday's law. This was Sarah's fifth time teaching Faraday's law but she continued to rely on the textbook that she used to plan her lesson to inform her what content she was expected to teach.

> I used the textbook. I just look at what they have to know about the topic and then YouTube videos. (post-i, 12-13)

Sarah was still unsure of certain concepts such as Lenz's law, admitting in her post-interview that she did not understand it (177-180) even though she knew that the curriculum stated "something" about the law (288).

A representation of both the RHR and Faraday's law were performed for learners which is required by the curriculum. However, there were drawbacks to Sarah's representation of Faraday's law which were that it did not allow learners to physically observe induction and that it included the idea of mutual induction which is beyond the scope of the curriculum.

It was evident from Sarah's lesson as well as her responses in the post-interview that she felt it was important for learners to understand that induction is based on the rate of change of flux, an idea which the curriculum indicates should be stressed by teachers. She was asked to explain what she understood as the expectation from the statement: "State Faraday's law", stated in the curriculum. She pointed out that learners must understand "the relationship between the EMF and, basically that it's directly proportional to the rate of change of magnetic flux" (31-32). This was again pointed out in her post-interview:

> It's because there's a change in the magnetic field that you get an induced EMF. And how fast this change is happening. (113-115)

The curriculum does not suggest how learners should be involved in lessons or the type of questions that teachers should ask them. The expert CoRe suggests that learner involvement should take place during demonstrations of the RHR and Faraday's law where teachers ask learners about their observations. Sarah's lesson lacked learner involvement as she explained to the class what learners should observe during the demonstrations of the RHR and induction rather than asking learners questions. Sarah only planned to specifically ask questions to address the one difficulty she was aware of regarding learners' ability to determine the angle required to calculate flux. For the rest of her lesson, learners needed to raise their hand to ask questions if they did not understand something. Sarah also kept all calculations for practice for the end once she had finished teaching the topic, rather than having learners practice the RHR or calculations after teaching each key idea before moving on to the next.

6.6 CASE STUDY 4: LINDA

Linda began teaching the topic of Electromagnetism which included Faraday's law to her class in the lesson that I observed. A vignette of this lesson is given below.

Linda began her lesson by revising the definition of electric field and magnetic field. She informed learners that they had previously studied the topics of Electricity and Magnetism separately but that they would see in the lesson that they have an effect on each other. She recalled that learners had in Grade 10 observed that current had a heating effect. She stated that they would be looking at the magnetic effect of current and eventually at Faraday's law of induction. She projected a PowerPoint presentation which had a short explanation of Faraday's law of electromagnetic induction and explained that it is used for predicting how a magnetic field will interact with an electric circuit to produce an emf. She explained that they were looking at Faraday's law because it is the fundamental operating principle of transformers, electric motors, generators, and solenoids and that learners would be going into detail of motors and generators the following year. Linda played a video clip

which demonstrated the effect on an electrical conductor in the presence of a magnetic field. The video clip showed a piece of wire that began to swing between the poles of a U-shaped bar magnet when a current was passed through the wire. She asked learners to observe what they saw. A learner replied that the conductor moved around in circles. Linda clarified that the wire moved towards the back of the magnet. She explained that it was important to note that the wire moved when current was flowing through it. She asked learners to explain why it moved, hinting that they should keep mechanics in mind. A learner stated that something will move if there is a force acting on it. Linda explained that the magnetic field is exerting a force on the conductor but only when the conductor is carrying current. She explained that learners could now see that a magnetic field can also exert a force on a magnetic object as well as charges but only if the charges were moving. Linda demonstrated the RHR for determining the direction of the magnetic field produced around a wire conductor. She then drew a diagram of a cross-section of wires and drew a dot inside the wire on the left and a cross inside the wire on the right. She explained that a dot and a cross are used to represent the direction of current. She returned to the RHR and showed learners how to use it to find and draw in the direction of the induced magnetic field around the wires. She explained that the two magnetic fields of the wire and the magnet were reacting to each other causing the wire to be pushed away. She said that this brought her to another concept which was if you have a conductor in a magnetic field and you move it, the magnetic field will induce a current in a conductor. A slide that had the equation for Faraday's law was put up. Linda explained that the "ε" in the equation meant the same thing as potential difference measured in volts. She stated the formal definition of Faraday's law for learners and then asked them to identify what was familiar to them in the equation. A learner replied that time was familiar. Another slide was shown to learners of a bar magnet and she said she would return to Faraday's law later. This slide was used to explain magnetic flux. She stated that magnetic flux, as seen in Faraday's law was the total number of magnetic field lines passing through an area. The diagram of the bar magnet had two circles, each encompassing a different number of field lines which she used to further explain magnetic flux. She wrote on the board the formula for magnetic flux, placing a delta sign in front of the formula and stated that learners would be working with a change in magnetic flux for Faraday's formula. Linda explained the difference between magnetic flux density which she said meant the same thing as magnetic field strength, and magnetic flux. She explained that if the magnetic field strength is multiplied by the area, magnetic flux will be obtained, emphasising that the field lines must past perpendicularly through the area. A slide was put up which was used to represent the different factors that influence the emf such as area, field strength, and orientation. Learners identified that the conducting loops on the right hand side of the diagram had a greater magnetic flux because more field lines passed through them. Linda explained that in order for learners to understand the purpose of the diagram, she first needed to explain that they would be looking at conducting loops that are moving in magnetic fields and that the flux would be the lines cutting through them. She explained that if the loop moves from the vertical in the diagram she had up, fewer lines would pass through the loop and so the flux would be lower. She showed learners on another slide how diagrams of conducting loops and magnetic fields could be shown to learners from another perspective. Another slide of a conducting loop at an angle to the magnetic field was used to explain how to calculate magnetic flux. Linda explained the concept of a normal of a loop. She stated that maximum flux is achieved if the loop is 90 degrees to the magnetic field but that this wasn't always the case. She explained that they were interested in finding the component of the magnetic flux that was passing perpendicularly through the loop using the cosine trigonometric function. She asked learners to calculate the value of cos90 and cos0. She drew conducting loops at different angles to magnetic field lines to relate the angle to the value of the magnetic flux. She said that students should not get confused between the angle at which they find the coil and the angle θ. She returned to the formula for Faraday's law and explained what each variable stood for. She had an induction torch which she explained had copper wires inside which were known as a solenoid. Inside the solenoid was a cylindrical magnet. She explained that when she shook the torch, there was a change in the magnetic flux as the magnetic field lines were cutting through the wires which generated a potential difference. Learners were able to see the flash of the lightbulb every time the torch was shook. She explained that there was only light when there was movement which is what Faraday's law was about. If you move a magnetic field through a conductor like a solenoid or when you move the loop in the magnetic field, it induces a potential difference that will eventually give you current. Linda referred learners to their textbook where she completed a question with learners for practice on calculating induced emf using Faraday's law.

Vignette: Linda's lesson

6.6.1 Curricular Saliency

Linda introduced the same key ideas in her lesson of 'Faraday' law' and 'Magnetic flux' which appear in the curriculum. Her sequencing differed from that in her reported PCK as she first introduced Faraday's law, stating it for learners before discussing magnetic flux. This is the same sequencing as in the curriculum. She did not select 'The phenomenon of induction' as a key idea in her reported PCK, neither was it a key idea present in her lesson. Linda demonstrated induction with an induction torch but only after she introduced Faraday's law and magnetic flux. Thus her demonstration was of Faraday's law in action rather than a demonstration of the phenomenon of induction.

In her post-interview (53), Linda stated that she would follow the same sequencing as that of the curriculum in which Faraday's law is stated before the concept of magnetic flux is introduced. She also confirmed that her lesson followed the same sequence. She did not seem to realise that a more conceptual sequence would be to introduce magnetic flux before stating Faraday's law as suggested by the expert CoRe. This was despite the fact that she was aware that Faraday's law only made sense to learners once she returned to discuss it after having introduced the concept magnetic flux. She stated: "I spent a lot of time on magnetic flux because it's a totally new concept to [learners]. And then I went back to Faraday's law which makes more sense to them" (55-57).

The concept of Lenz's law was discussed in a following lesson after Linda finished teaching the topic of Faraday's law (pre-i, 264-265). She was aware that the idea stated in the curriculum of "the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux" relates to Lenz's law (post-i, 245-257) but that the curriculum does not expect teachers to teach the law itself (261-263). Linda, however, was unable to recognise that the formula for Faraday's law acknowledges Lenz's law due to the presence of the negative sign in the formula (257-260).

6.6.2 What is Difficult to Teach?

The curriculum's explanation of how to apply the RHR suggests that learners may have difficulties in applying it. It appeared that Linda did not teach learners how to determine the direction of the induced current using the RHR. As she had not demonstrated it for learners in her lesson that I observed, she was asked in her post-interview (260-264) if she had shown it in a following lesson that I had not observed. She stated that "the Right-Hand Rule was taught in the section of current-carrying conductors, before Faraday's law" (post-i, 265-266). The RHR she is referring to is the one used to determine the direction of the induced magnetic field around a straight conductor which she taught in the lesson I observed. As a result, she did not address the difficulty of which magnetic field to apply the RHR to. Her restricted knowledge of the content may have prevented her from realising that there are different versions of the RHR which must be taught to learners.

Linda noted in her post-interview that the topic of Faraday's law contained many new concepts such as magnetic flux (post-i, 55-56) and Lenz's law (173-175) which makes it difficult to teach. The nature of the topic of Faraday's law as being difficult due to the number of new concepts is not discussed in the curriculum but the expert CoRe does specifically indicate that magnetic flux is a difficult concept as learners have not been taught the concept before. Linda expressed her wish for learners to be introduced to this concept earlier on in Grade 10 but did not suggest ways she would teach these concepts currently in Grade 11 to address difficulties regarding these concepts.

6.6.3 Learners' Prior Knowledge and Misconceptions

Linda was cognisant that learners had studied Magnetism in Grade 10 but felt that the topic and its content did not influence her teaching to a large extent due to it being covered on a basic level in Grade 10 (post-i, 22-23). She felt that the curriculum does not explain the meaning of magnetic field or refer to it as magnetic field strength. This prompted her to explain the concept of magnetic flux density in her lesson. This may confuse learners since the term is very similar to magnetic flux even if they are related. Important pre-concepts such as field line properties and misconceptions related to them were discussed. Importantly, Linda did relate emf to potential difference studied in Grade 10 although no other concepts from Electricity were revised.

Linda indicated in her pre-interview that learners may find Faraday's law difficult as they were not aware that magnetism and electricity are related. However, important pre-concepts from these prior topics were not revised with learners. Instead, she appeared to be more concerned with how Faraday's law relates to the Grade 12 topic of Motors and Generators (post-i, 21-22). She included Grade 12 content in her lesson regarding the force exerted in a conductor and mentioned teaching Fleming's left and right hand rules in her CoRe. These ideas are not necessary for the understanding of Faraday's law which forms the basis for these future topics.

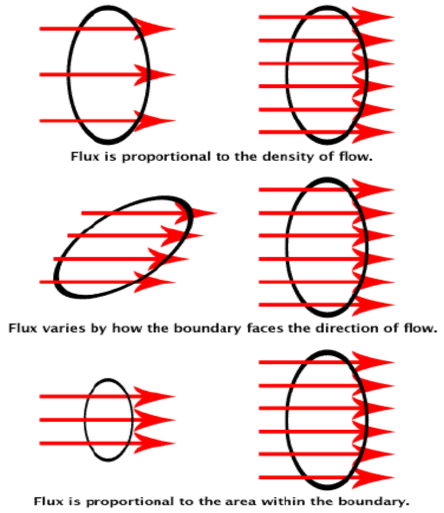
Concepts from the Grade 10 topic of Energy such as energy conversions and the Law of Conservation of Energy are relevant to Faraday's and Lenz's law. These concepts were not discussed by Linda. They are, however, also not mentioned in the curriculum.

6.6.4 Representations

As previously discussed, Linda did not explain how to apply the specific version of the RHR used to determine the direction of the induced current even though this rule is discussed in the curriculum. She stated in her post-interview (172-173) that learners should already know how to apply the RHR before explaining a demonstration of induction. The only RHR that learners will have been taught before a demonstration of induction is the version used to determine the direction of the induced magnetic field. This particular version of the RHR demonstrated by Linda is not explained in the curriculum whereas the RHR used to determine the direction of the induced current is.

Linda was asked if she had explained to learners what happens when a bar magnet is pushed into or pulled out of a solenoid as expected by the curriculum. This demonstration of Faraday's law was not shown to learners as Linda said she had never seen a galvanometer in the 25 years she had been teaching (post-i, 37-40). It appeared that she was not aware that a galvanometer is a type of ammeter, a common apparatus in school laboratories. Linda's only representation of induction and Faraday's law was that of an induction torch which she showed learners at the end of the lesson once she had taught all the concepts related to Faraday's law. This demonstration was not used to support learners' understanding of Faraday's law but rather as visual evidence of induction. Linda came to realise the importance of a demonstration of induction during her post-interview. She indicated that she would teach the topic differently in future by making a greater concerted effort to acquire the apparatus listed in the curriculum in order to demonstrate induction or find a YouTube video that illustrates it (post-i, 269-271). However, she still did not demonstrate an understanding for the apparatus listed in the curriculum and how they could be used to support the understanding of certain concepts such as change in flux.

No representations to explain magnetic flux are mentioned in the curriculum. Linda used a variety of images such as those shown in figures 6.4 and 6.5 to explain the concept. Linda stated that she "spent a lot of time on magnetic flux because it's a totally new concept to [learners]" (post-i, 55-56). Such diagrams are important even though no representations for magnetic flux are discussed in the curriculum. One drawback of Linda's diagrams for magnetic flux is that they did not allow learners to visualise three-dimensional vectors and angles due to the nature of the two-dimensional images.



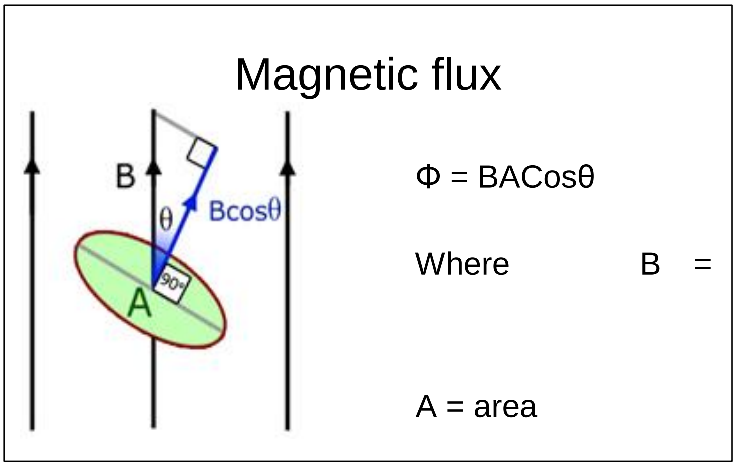


Figure 6.4: Diagram used to explain variables that influence magnetic flux

Figure 6.5: Diagram used to explain magnetic flux

6.6.5 Conceptual Teaching Strategies

Instead of introducing the broader topic of Electromagnetism and the induction of magnetic fields by currents in a separate lesson, Linda taught them in the same one hour lesson in which she introduced Faraday's law. This is in spite of the fact that the curriculum allocates six hours to the entire topic of Electromagnetism. Her key ideas: (A) 'The magnetic effect of current', and (B) 'The effect of magnetic field on current' from her CoRe were thus briefly explained. As a result, she did not teach all the concepts expected by the curriculum for these key ideas which are needed later on for the understanding of Faraday's law.

Linda's sequencing of key ideas in her lesson gave a false impression that Faraday's law explains the entire topic of Electromagnetism and the relationship between magnetic fields and current. She started off the entire topic of Electromagnetism by first discussing Faraday's law before returning to discuss the induction of magnetic fields by currents. These ideas relate to two separate sections in the topic of Electromagnetism in the curriculum. She was asked in the post-interview if she would introduce the concepts in the same order as alluded to in the curriculum. She stated: "I think that's exactly what I did. I gave them an overview of Faraday's law. They haven't got a clue what it means. Then you break it down" (53-54). Her sequencing of key ideas, however, was not entirely the same as implied in the curriculum. Linda did indeed begin by explaining Faraday's law but only demonstrated induction at the end of the lesson once she had already introduced the concept of magnetic flux. This is not an effective sequencing as learners should rather be shown a demonstration of induction at the beginning of teaching Faraday's law. This would allow learners to intuitively come to understand the need for the concept of magnetic flux in order to understand how induction occurs.

The greatest drawback of Linda's lesson is that she did not explain the correct version of the RHR which is a demonstration explained in the curriculum. She also did not adequately demonstrate Faraday's law. The induction torch that she used to demonstrate induction did not allow learners to see the circuit components inside the torch such as those listed in the curriculum. Linda also did not draw any diagrams of magnets being pushed into or pulled out of solenoids which prevented learners from relating what they should observe during a demonstration with an explanation of induction. Linda regarded representations of magnetic flux as most important as it is an underlying concept in Faraday's law and is also a concept that learners have never come across before. This prompted her to use a variety of images to explain the concept with little focus on representations of induction.

The curriculum is regarded as indicating that, as part of a conceptual teaching strategy, teachers should stress the idea that the induced emf depends on the rate of change of magnetic *flux*. Linda did point this idea out during her lesson, stating:

> [Faraday's law] tells you that an emf will be induced if you move a conductor in a magnetic field. And that induced emf will be directly proportional to the rate of change of magnetic flux. …If the coil is moving through those lines, the magnetic flux is changing.

Linda indicated in her post-interview that she wanted learners to understand the concept of electromagnetic induction and its associated concepts "from the beginning to the end" (175-176) which led her to teaching the entire topic of Electromagnetism in a one hour lesson. This lesson both covered the first sub-topic of 'Magnetic fields associated with current carrying wires' (which is allocated three hours in the curriculum) as well as the sub-topic of Faraday's law (also allocated three hours in the curriculum). This decision to compress so many new concepts for a topic which is considered difficult for learners into a single lesson will not have given learners time to fully understand Faraday's law. As a result, her lesson had very little learner involvement due to the lecture style teaching that she employed in her lesson. This limited her ability to assess learners' understanding of the individual concepts taught before she moved on to a new concept. The curriculum does not discuss learner involvement or the type and quantity of practice teachers should have learners do. Linda came to realise after teaching her lesson that these are important aspects of an effective conceptual teaching strategy, stating in her post-interview that:

> In retrospect if I did it again, I've put a lot of content into one period and it was basically a lecture. ...If I have time [in future] I would like to break it down into smaller pieces and give them a question on every aspect and see whether they can cope with that before I proceed to the next concept. (173-179)

6.7 SUMMARY

This chapter presented an analysis of the teachers' lesson presentations and post-interviews. An overview of how the data was analysed in relation to the curriculum through the components of TSPCK was provided. Each teacher's lesson was discussed separately, beginning with a vignette for an overall view of the sequence and content of the lesson. This was followed by an analysis of the lesson, particularly focusing on the alignment or deviation with the information provided in the curriculum through the components of TSPCK.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 INTRODUCTION

Chapter Four of the current study presented an analysis of the information contained in the curriculum to produce the 'expert curriculum interpretation'. In Chapters Five and Six, the reported PCK of the participating teachers as well as their interpretation of the curriculum were characterised respectively. This chapter presents a discussion on the findings of the four cases in relation to the primary research question: How can selected teachers' enactment of the curriculum on Faraday's law be understood in relation to their reported PCK? The chapter concludes with an outline of suggestions for future research and recommendations based on the findings of this study.

7.2 COMPARING TEACHERS' INTERPRETATION OF THE CURRICULUM AND THEIR REPORTED PCK

Each case study comparing the teachers' interpretation of the curriculum with their reported PCK is presented separately as in a multi-case study. The analysis looked for illustrative cases in which the quality of reported PCK indicated how the curriculum was understood as reflected in their teaching and interviews. The comparisons are presented in terms of four of the five components of TSPCK which were used to characterise both the teachers' reported PCK as well as the information contained in the curriculum on Faraday's law. The component of *conceptual teaching strategies* is not discussed in the results as it draws on the previous four components of PCK. Thus, the teachers' interpretation of the curriculum was analysed in terms of the four components that are brought together in *conceptual teaching strategies*.

7.2.1 Michelle

7.2.1.1 Curricular saliency

Michelle's lesson only included the two key ideas evident in the curriculum: 'Magnetic flux' and 'Faraday's law'. 'The phenomenon of induction', a key idea in the expert CoRe, was not presented in her lesson. However, Michelle demonstrated an insightful interpretation of the curriculum based on the concepts she presented in her lesson and her sequencing thereof. She introduced magnetic flux before Faraday's law which is the same sequence given in the expert CoRe but different to the curriculum. The curriculum implies that flux be introduced after Faraday's law. An extension of the curriculum was also present in her lesson, with Michelle stating Lenz's law for learners. The concept of Lenz's law is mentioned in the curriculum although not by name. Her extension of the curriculum and sequencing reflected her Developing (3) competence in terms of *curricular saliency* in her reported PCK. Michelle's reported PCK suggested that she would further extend the curriculum by including the key idea of 'The phenomenon of induction' with a demonstration before discussing Faraday's law although this did not appear in her lesson. Although Michelle did not extend the curriculum, she did include the same conceptually effective sequencing of key ideas in her lesson as well as mentioned Lenz's law and its relationship with the RHR. The textbook Michelle used to plan her lesson, however, had an influence on her lesson which suggests that her conceptually effective sequencing was not informed by her PCK. This was evident in her statement that she chose to teach flux before Faraday's law and state Lenz's law because of the contents and sequence presented in the textbook rather than being aware that Lenz's law is discussed in the curriculum. This suggests that these variations from the curriculum were ultimately influenced by the textbook rather than her interpretation of the expectations of the curriculum.

7.2.1.2 Learners' prior knowledge and misconceptions

Current, emf, and magnetic field lines are concepts mentioned in the section of Faraday's law in the curriculum although it does not explicitly point out that these are pre-concepts, nor does it discuss related misconceptions. Pre-concepts related to energy are not mentioned in Faraday's law in the curriculum. However, these pre-concepts related to energy are regarded as relevant prior knowledge for the topic in the expert CoRe. Michelle's lesson showed poor curriculum interpretation as the extent to which she incorporated learners' prior knowledge only included revising properties of magnetic field lines. She also did not address any misconceptions in her teaching. The poor interpretation of the curriculum by Michelle aligned with her Basic (2) competence in terms of prior knowledge in her reported PCK. She identified the topic of Magnetism as a relevant prior topic which was reflected in her lesson. Similar to the curriculum, Michelle did not report any prior knowledge of concepts related to the topic of Energy and thus no extension of the curriculum was evident. As in her lesson, Michelle also did not discuss any misconceptions related to learners' prior knowledge. Michelle's lesson and thus her interpretation of the curriculum closely resembled her reported PCK for this component as seen from the absence of misconceptions identified or addressed as well as the few pre-concepts which she revised.

7.2.1.3 What is difficult to teach?

Although the curriculum is not explicit about what is difficult in Faraday's law, it provides guidelines for teaching concepts documented as difficult in the literature. One such concept is the application of the RHR to determine the direction of the induced current. Michelle's lesson demonstrated an insightful interpretation of the curriculum from her use of diagrams of conducting loops and magnets to address the difficulty alluded to in the curriculum. These diagrams were also used to explain the RHR to reinforce which magnetic field the rule needed to be applied to, thus extending the curriculum which does not clearly explain how this rule should be applied. Michelle's adaption of the curriculum aligned with her Developing (3) competence in terms of difficulties indicated in her reported PCK. She revealed awareness of the challenges associated with the relationship between the direction of the induced magnetic field and current as well as difficulty in applying the RHR, the same challenges that she addressed in her lesson.

7.2.1.4 Representations

The curriculum lists the following apparatus that teachers should use to perform a practical demonstration of Faraday's law: solenoid, bar magnet, galvanometer, and connecting wires. Michelle represented Faraday's law using a bottle and a pencil to represent a solenoid and a bar magnet, respectively, during her lesson. This revealed a misinterpretation of the curriculum and thus prevented learners from making important observations listed in the expert CoRe regarding induction such as the deflection of the needle in a galvanometer. Furthermore, she used the same unsuitable objects to demonstrate how the RHR is used to determine the direction of the induced current, in an attempt to follow the recommendation in the curriculum.

Nevertheless, she enriched the curriculum by using drawings of diagrams similar to those in the expert CoRe to explain magnetic flux at different angles while the curriculum does not refer to the use of representations to support the discussion of magnetic flux. Michelle's lack of insight regarding important representations referred to in the curriculum reflects her Basic (2) competence in terms of *representations* in her PCK. Her reported PCK inadequately described the use of a crucial demonstration to explain Faraday's law, seemingly because of her misinterpretation of the focus of Faraday's law. Her reported PCK revealed that she was of the belief that the induced current and its direction was the primary focus of Faraday's law. As such, she used objects which focused on explaining the RHR rather than understanding how induction occurs in her lesson. Her reported PCK included representations of magnetic flux which are not mentioned in the curriculum which were evident in her lesson. However, these too were inadequate as they did not clearly represent the three-dimensional nature of conducting loops in magnetic fields which may confuse learners as to how to determine the angle needed to calculate magnetic flux.

7.2.1.5 Summary

Michelle was scored Developing (3) for both the components of *curricular saliency* and *what is difficult to teach*. Her lesson revealed insightful interpretation of both of these components as well. Although Michelle scored high in the component of curricular saliency, the influence of the textbook on her interpretation of the curriculum was evident. For the component of *representations*, Michelle's knowledge was scored as Basic (2) which was evident in her lesson due to the absence of effective representations.

7.2.2 Tebogo

7.2.2.1 Curricular saliency

Tebogo's lesson demonstrated an in-depth interpretation of the curriculum as his lesson included both key ideas present in the curriculum; 'Magnetic flux' and 'Faraday's law' but further extended it by including 'The phenomenon of induction' similar to the expert CoRe. His lesson followed a similar sequence to the curriculum, introducing Faraday's law before magnetic flux. Although this sequence is regarded by the expert CoRe as less conceptually effective, Tebogo was of the opinion that by stating Faraday's law first, learners would understand the reason for the need for the concept of flux. His sequence bore in mind flux as an important concept needed to understand induction and not only as a value needed to calculate the induced emf. Thus, his sequence was considered effective. Similar to the curriculum, Tebogo did not state Lenz's law or mention its name. Instead, he applied it alongside the RHR to determine the direction of the induced current. His extension of the curriculum and sequencing aligned with his Developing (3) competence in terms of *curricular saliency* in his reported PCK. He identified the same key ideas which were also present in his lesson which included 'The phenomenon of induction', an idea that is not evident in the curriculum. Like in his lesson, his reported PCK emphasised having learners first observe the phenomenon of induction. He did not discuss Lenz's law in his reported PCK. Regarding Lenz's law, Tebogo interpreted the curriculum adequately by extending it to include the key idea of 'The phenomenon of induction' in his lesson but did not include important concepts implicitly referred to in the curriculum. His post-interview revealed that he was aware that the concept of Lenz's law is discussed in the curriculum but since the curriculum did not indicate that the law must be stated for learners, he did not mention it.

7.2.2.2 What is difficult to teach?

The curriculum provides guidelines for teaching concepts documented as difficult in the literature. One such concept is the application of the right-hand rule to determine the direction of the induced current in a solenoid. Tebogo showed insightful interpretation of the curriculum as he was aware that it refers to different versions of the RHR but does not distinguish between them which could result in its application being difficult for teachers and learners. He clarified this in his lesson by explicitly stating what the thumb and fingers represent for the RHR discussed in Faraday's law in the curriculum. He extended the curriculum and the difficulties alluded to in it by addressing two other difficulties in his lesson related to learners' tendency to confuse the concept of magnetic field with magnetic flux as well as their poor ability to visualise in three dimensions. Tebogo pointed out in his lesson that flux is specifically a quantity that needs to be calculated as well as performing a demonstration mentioned in the expert CoRe using a pen and piece of paper to explain how magnetic flux is calculated.

Tebogo's interpretation and extension of the curriculum aligned with his Developing (3) competence in terms of difficulties in his reported PCK. He identified two major difficulties which related to learners' ability to visualise in three dimensions as well as their ability to apply the RHR, both of which he addressed in his lesson. His reported PCK also revealed that he planned to extend the curriculum by testing learners on a variety of different calculations for change in flux calculations other than for a change in magnetic field strength. The curriculum states that the only variable that learners will calculate a change in magnetic flux for, is a change in magnetic field strength. However, Tebogo was aware that in assessments, leaners could be expected to calculate the change in flux for different variables such as orientation or area size of the conductor.

7.2.2.3 Learners' prior knowledge and misconceptions

Although the curriculum does not explicitly state relevant prior knowledge for Faraday's law, the concepts of magnetic fields, emf, and current are mentioned. Tebogo explicitly drew on learners' prior knowledge of emf and current in his lesson to remind them of their meaning. He enriched the curriculum by adding calculations involving Ohm's law in an exercise he created for his learners. Ohm's law is not mentioned in the section of Faraday's law but is included in the expert CoRe. Concepts from the topic of Magnetism were not explicitly revised during his lesson but he noted in his post-interview the importance of this topic for learners' understanding of Faraday's law. He further enriched the curriculum by addressing one misconception regarding relative motion between a conductor and magnet which is not alluded to in the curriculum but is mentioned in the expert CoRe. Like its absence in the curriculum, his lesson did not include concepts from the topic of Energy to explain Faraday's or Lenz's law. Despite excluding the pre-concepts of energy, Tebogo's interpretation did not align with his Basic (2) competence in terms of *learners' prior knowledge and misconceptions* as he demonstrated a more in-depth interpretation. His reported PCK revealed relevant prior knowledge only pertaining to the topic of Magnetism whereas his lesson included prior knowledge from the topic of Electric Circuits as well. He also addressed a misconception related to the relative motion between a magnet and conductor during his lesson which he did not identify in his reported PCK.

7.2.2.4 Representations

During his lesson, Tebogo demonstrated an insightful interpretation of the curriculum. He showed learners a video of induction which included the same apparatus as those listed in the curriculum and also drew learners' attention to certain observations which are regarded as important in the expert CoRe, for example the deflection of the needle. Tebogo explained the RHR during his lesson in a similar way to which it is explained in the curriculum but further extended the curriculum by clarifying which magnetic field to apply the rule to, thus addressing a difficulty mentioned in the expert CoRe. The curriculum does not prescribe representations for magnetic flux. However, Tebogo performed a demonstration that is described in the expert CoRe to explain the concept to leaners which involves using a pen and a piece of paper to explain the normal direction of a loop and how it is used to determine the angle required to calculate flux. His interpretation of the curriculum aligned with his Developing (3) competence in terms of representations in his reported PCK. Tebogo's reported PCK revealed knowledge of both representations discussed in the curriculum regarding the RHR and induction as well as important observations learners should make from a demonstration of induction. He also discussed a representation to explain magnetic flux and how the angle for flux is determined, the same representation which he used in his lesson.

7.2.2.5 Summary

Tebogo scored the highest overall of all the participants for his reported PCK. His interpretation of the curriculum for three components of PCK aligned with his level of competence in that component with the exception of *learners' prior knowledge and misconceptions*. His interpretation of the curriculum went into greater depth than his knowledge reflected in his reported PCK for this component. This was also the component in which Tebogo scored the lowest, which may have been as a result of him not fully expressing his knowledge regarding this component in his reported PCK.

7.2.3 Sarah

7.2.3.1 Curricular saliency

Sarah interpreted the curriculum at face value as her lesson included the same key ideas of ‘Magnetic flux’ and ‘Faraday’s law’ in the curriculum, whereas ‘The phenomenon of induction’ was not present. However, she adapted the curriculum by introducing magnetic flux before Faraday’s law which is regarded as more conceptually effective by the expert CoRe. Sarah was not aware that the concept of Lenz’s law is discussed in the curriculum, stating to her class that they would learn about it in university. She briefly discussed how the negative in the equation of Faraday’s law related to Lenz’s law but only because she was asked about the negative by a learner. Sarah’s interpretation of the curriculum reflected her Basic (2) competence in terms of *curricular saliency* in her reported PCK. She identified two key ideas, ‘Magnetic field’ and ‘Magnetic flux’ in her reported PCK of which only the latter is a relevant key idea in Faraday’s law according to the expert CoRe. Sarah’s reported PCK revealed that she would introduce flux before Faraday’s law as she did in her lesson. However, she had chosen this sequencing as it was the sequence present in the textbook which she used to plan her lesson. She was not confident as to which sequencing between that of the textbook and curriculum would be more effective, stating in her post-interview that the curriculum’s sequence may be better without providing reasons why. Her reported PCK also did not reveal knowledge of Lenz’s law. Sarah admitted in her post-interview that she did not understand Lenz’s law. Her poor interpretation of the curriculum by failing to recognise that Lenz’s law is implicitly referred to in it reflected her limited PCK about this idea.

7.2.3.2 What is difficult to teach?

Sarah extended the curriculum by addressing two difficulties in her lesson which are not alluded to in it. The first difficulty relates to learners’ ability to visualise in three dimensions with regard to determining the angle needed to calculate magnetic flux. The second difficulty relates to learners’ limited understanding that the mere existence of a magnetic field through a coil does not induce an emf. Sarah also briefly addressed the difficulty associated with the RHR alluded to in the curriculum by specifying that the RHR must be applied to the induced magnetic field and not the field of the magnet.

Sarah’s extension of the curriculum reflected her Developing (3) competence in terms of *what is difficult to teach* in her reported PCK. She revealed knowledge of the same two difficulties which she addressed in her lesson, both of which are included in the expert CoRe. She also revealed that because magnetic fields are invisible, learners’ have difficulty with understanding that a change in magnetic flux is needed to induce an emf. This difficulty is also included in the expert CoRe.

7.2.3.3 Learners’ prior knowledge and misconceptions

Although relevant prior knowledge is not explicitly mentioned in the curriculum, the concepts of magnetic fields, emf, and current are. Sarah specifically revised the concepts of magnetic fields and emf and further extended the curriculum by drawing on learners’ knowledge of Ohm’s law to guide them during an exercise. Relevant prior knowledge relating to the topic of Energy which the curriculum does not allude to was not evident in Sarah’s lesson. Sarah’s interpretation of the curriculum in her lesson was more insightful and did not reflect her Basic (2) competence in terms of *learners’ prior knowledge and misconceptions* in her reported PCK. In her reported PCK, she only identified prior knowledge from the topic of Magnetism, whereas her lesson included pre-concepts from the topic of Electric Circuits as well. Sarah revealed knowledge of one misconception in her reported PCK which related to learners’ conception of magnetic field lines, stating that it is important for learners to understand that magnetic field lines are imaginary lines. Her lesson, however, did not reveal further knowledge of misconceptions.

7.2.3.4 Representations

Sarah’s lesson included both representations prescribed by the curriculum relating to the RHR and Faraday’s law, with a slight deviation in terms of Faraday’s law. Instead of using the physical apparatus of a solenoid, a galvanometer, a magnet, and connecting wires, she drew a setup on the board of an experiment performed by Faraday which is beyond the scope of the curriculum in terms demonstrating mutual induction. Sarah, however, demonstrated an adequate interpretation of the curriculum as she was aware of the importance of the apparatus listed in it and how they are used to make specific observations from the demonstration of induction. Such observations, for example the deflection of the needle, are not described by the curriculum. She also extended the curriculum by including representations of magnetic flux in her lesson. Sarah's interpretation of the curriculum was insightful and did not reflect her Basic (2) competence in terms of *representations* in her reported PCK. Her knowledge of representations strongly focused on the concept of magnetic flux while important representations of induction and the RHR were not mentioned. She also indicated in her reported PCK that she would only show representations of Faraday's law after teaching the topic but deviated from this by describing the experiment that was originally performed by Faraday in her lesson to introduce the concept of induction.

7.2.3.5 Summary

Sarah's interpretation of the curriculum reflected her reported PCK for the components of *curricular saliency* and *what is difficult to teach*. For *curricular saliency*, however, it was observed that the sequencing of concepts in her lesson was influenced by the textbook that she used to plan her lesson. Sarah also showed an insightful interpretation of the curriculum for the components of *learners' prior knowledge and misconceptions* and *representations*, which did not align with her reported PCK for these components.

7.2.4 Linda

7.2.4.1 Curricular saliency

Linda's lesson included the key ideas of 'The magnetic effect of current' and 'The effect of magnetic field on current' as in her CoRe. These are not considered key ideas in Faraday's law according to the expert CoRe, but rather pre-concepts and future knowledge respectively. The key ideas of 'Magnetic flux' and 'Induced emf' in the curriculum were present in her lesson but 'The phenomenon of induction' from the expert CoRe was not. Linda followed the curriculum's sequencing by introducing Faraday's law before flux. Her sequencing, however, was chosen in order to make learners aware of which values are needed to calculate the induced emf rather than to support understanding of induction. Lenz's law is not referred to by name in the curriculum but it is included in the expert CoRe. Following the curriculum, Linda discussed the concept of the direction of induced current but did not state the law similar to the curriculum. Linda's face value interpretation of the curriculum can be attributed to her Basic (2) competence in terms of *curricular saliency* in her reported PCK. The same four key ideas that were present in her lesson were selected by her as key ideas in her reported PCK. Having stated that learners struggle to understand how magnetism and electricity are related, she selected key ideas not directly related to Faraday's law. Instead, key ideas related to magnetic fields associated with current carrying conductors were selected. This is a separate sub-topic of Electromagnetism in the curriculum and thus its key ideas are better suited for introduction in a separate lesson prior to Faraday's law. In her reported PCK, she described a sequence regarded as conceptually effective by the expert CoRe but deviated from this in her lesson by following the curriculum's sequence at face value. This is due to the fact that she did not deviate from the sequencing implied in the curriculum or recognise that an alternative sequence was possible that would be more effective for conceptual understanding.

7.2.4.2 What is difficult to teach?

Linda extended the curriculum by addressing a difficulty in her lesson which related to learners' ability to determine the angle needed to calculate magnetic flux. However, Linda did not address the difficulty regarding which magnetic field to apply the RHR to for Lenz's law. She was under the impression that the RHR used for Lenz's law to determine the direction of the induced current is the same RHR used to determine the direction of the induced magnet field around a straight conductor. This is in spite of the fact that the RHR used for Lenz's law is described in the curriculum. Linda presented a poorer interpretation of the curriculum than what can be attributed to her Developing (3) competence in terms of *what is difficult to teach* in her reported PCK. In her reported PCK, Linda noted the numerous new concepts that learners are introduced to in Faraday's law, which contribute to the difficulty in understanding. However, her lesson of one hour covered the entire topic of Electromagnetism which is allocated six hours in the curriculum. Thus, many new concepts were taught in a short period of time. Linda also noted in her reported PCK that learners struggle to visualise abstract concepts which require the use of three-dimensional representations. Her lesson, however, only used two-dimensional diagrams to explain concepts such as flux.

7.2.4.3 Learners' prior knowledge and misconceptions

Although the curriculum does not explicitly describe relevant prior knowledge for Faraday's law, concepts such as magnetic field lines, current, and emf are mentioned. Linda mentioned magnetic field lines in her lesson but did not revise important concepts such as properties of field lines. This was similar to current and emf which she mentioned in her lesson but without drawing on learners' understanding to identify gaps and misunderstandings. Linda further demonstrated poor curriculum interpretation as concepts from the topic Energy and their misconceptions were not included in her lesson either. Linda's interpretation of the curriculum can be attributed to her Basic (2) competence in terms of *learners' prior knowledge and misconceptions* in her reported PCK. Linda was aware that the Grade 10 topic of Magnetism formed part of learners' prior knowledge but was of the opinion that since it was taught in such shallow detail, learners were not taught relevant pre-concepts for Faraday's law. She failed to recognise the importance of pre-concepts such as properties of magnetic field lines as in her lesson. Linda's reported PCK instead focused on concepts that are either taught later on in school or not at all which she felt needed to be taught earlier as she believed that they are important for understanding Faraday's law. These included Fleming's left and right hand rules, the heating effect of current, and flux density. These, however, are not relevant and would not aid conceptual understanding of Faraday's law.

7.2.4.4 Representations

Linda's lesson included representations of magnetic flux which are not described in the curriculum but are included in the expert CoRe. As for the RHR, Linda only demonstrated the version which is used to determine the direction of the induced magnetic field around a straight current carrying wire and not the version related to Lenz's law which is used to find the direction of the induced current. She did not appear to be cognisant of the fact that there are different versions of the RHR, depending on the shape of the conductor. For Lenz's law, Linda merely pointed learners to where the law is discussed in their textbook but did not explain to learners how to find the direction of the induced current in the solenoid with the appropriate RHR. As prescribed by the curriculum, Linda demonstrated induction using an induction torch but only at the end of the lesson and as a means of visual proof rather than to explain the law. Linda's inadequate interpretation of the curriculum can be attributed to her Basic (2) competence in terms of *representations* in her reported PCK. Her reported PCK revealed that she was aware that magnetic flux is a new and difficult concept for learners and thus it is important to use diagrams to explain the concept as she did in her lesson. However, like its absence in her lesson, she did not identify the RHR in her reported PCK. Instead, Linda discussed her wish for learners to be taught Fleming's left and right hand rules earlier. These rules would not aid understanding of Faraday's or Lenz's law. Her interpretation of the curriculum regarding representations of Faraday's law can also be attributed to her reported PCK in which she chose to use an induction torch only for demonstration purposes. This may be attributed to the curriculum that states that a practical demonstration of Faraday's law be shown to learners but does not describe how such a demonstration should be used to explain induction or important observations that should be made.

7.2.4.5 Summary

Linda generally demonstrated poor interpretation which could be attributed to her Basic (2) level of competence in all of the components of PCK with the exception of the component of *what is difficult to teach*. For this component, Linda was allocated a Developing (3) score but her interpretation of the curriculum did not match her level of competence. Although she identified important difficulties that learners have in Faraday's law, her interpretation of the curriculum revealed that she was not aware that the topic of Electromagnetism is separated into different sub-topics. These sub-topics are: The magnetic field associated with current carrying wires, and Faraday's law. These sub-topics are allocated a total of six hours in the curriculum but were taught in one hour by Linda.

7.3 DISCUSSION OF THE RESULTS

7.3.1 Secondary research question 1: How can the curriculum on Faraday's law be characterised in terms of the topic-specific PCK components?

7.3.1.1 Curricular saliency

Two of the three key ideas included in the expert CoRe are evident in the curriculum document. These are the key ideas of 'Magnetic flux' and 'Faraday's law' with the key idea of 'The phenomenon of induction' not explicitly referred to. The curriculum is regarded as suggesting a sequencing of these ideas that may not be effective for conceptual understanding according to the expert CoRe. In particular, the curriculum points out that Faraday's law should be stated before indicating that the concept of magnetic flux be introduced to learners. Visibly absent from the curriculum, which the expert CoRe indicates as important, is the knowledge that will aid the conceptual understanding of the induced current such as Lenz's law and the concept of an opposing induced magnetic field.

7.3.1.2 What is difficult to teach?

The curriculum document does not explicitly indicate concepts that are difficult for teaching or learning. Rather, certain information provided in the curriculum under the heading of 'Guidelines for teachers' is regarded as informing teachers' knowledge of difficulties. In particular, the curriculum explains the relationship between the direction of the induced field and the change in magnetic flux which suggests that learners may struggle with understanding this relationship. However, the role of energy and the application of prior knowledge to understand the direction of the induced current is not alluded to in the curriculum which may make explaining this relationship difficult. Other important difficulties according to the expert CoRe that are not alluded to in the curriculum relate to applying the RHR, understanding the vector nature of the area used to calculate magnetic flux, and visualising vectors in three dimensions.

7.3.1.3 Learners' prior knowledge and misconceptions

All content previously taught in the Physical Sciences curriculum is considered to be learners' prior knowledge, but the curriculum does not specify *what* prior knowledge is relevant to the learning Faraday's law. As a result, misconceptions related to learners' prior knowledge are not alluded to in the curriculum. Topics that learners have previously studied that contain pre-concepts that are essential for the understanding of Faraday's Law are Magnetism, Electric Circuits, and Energy. These topics are taught in Grade 10. Unlike pre-concepts from the topic of Magnetism and Electric Circuits whose terms are mentioned in the section of Faraday's law of the curriculum, pre-concepts from the topic of Energy are not. The Law of Conservation of Energy is important for understanding the reason why the induced current is set up in a direction so as to oppose the change in flux and thus understanding Lenz's law.

7.3.1.4 Representations

The curriculum states that a practical demonstration of Faraday's law must be performed for learners. It also includes the materials that are required for such a demonstration, which are a solenoid, bar magnet, galvanometer, and connecting wires. Teachers, however, will need to know how to set up the apparatus as well as what exactly should be explained and observed during this demonstration. Another representation discussed in the curriculum which the expert CoRe regards as important is that of applying the RHR.

Although magnetic flux is a new concept to learners, specific reference to representations that could be used to explain this concept are not mentioned in the curriculum. However, such representations are important in addressing difficulties with understanding and calculating magnetic flux.

7.3.1.5 Conceptual teaching strategies

The curriculum does not describe or prescribe a teaching strategy that teachers should follow. What is given in the curriculum, which should form part of a teacher's conceptual teaching strategy, are the representations of Faraday's law and the RHR. It also stresses that teachers should point out to learners that electromagnetic induction is based on the rate of change of flux.

An important concept which is not emphasised in the curriculum is the relationship between the direction of the induced current and the induced field. A conceptual understanding of this is important for allowing learners to understand both the reason why the induced field opposes the change in flux as well as why the current is generated in a specific direction. This would also allow for an understanding of the concept on which the application of the RHR is based.

7.3.2 Secondary research question 2: How can selected teachers' reported PCK about Faraday's law be characterised?

Generally, the teachers' reported PCK on Faraday's law was scored as Basic (2) with the average score for each teacher for all of the TSPCK components ranging between 2.2 and 2.8. The component which all of the participants scored the highest in was *what is difficult to teach* with a score of Developing (3) awarded to every teacher. The component which the participants scored the lowest in was *learners' prior knowledge and misconceptions* with every teaching receiving a score of Basic (2). For the components of *curricular saliency*, *representations*, and *conceptual teaching strategies*, the teachers received scores ranging from Basic (2) to Developing (3).

7.3.3 Secondary research question 3: How do the teachers' presentation of lessons on Faraday's law align to the curriculum, or deviate from it?

7.3.3.1 Curricular saliency

Sarah and Linda interpreted the curriculum at face value as only the two key ideas of 'Magnetic flux' and 'Faraday's law' present in the curriculum were evident in their lesson. Tebogo and Michelle interpreted the curriculum adequately due to their extensions of the curriculum which would aid conceptual understanding. Tebogo extended the curriculum to include the key idea of 'The Phenomenon of induction' while Michelle discussed Lenz's law in her lesson although the curriculum does not mention the law by name. Michelle and Sarah both deviated from the implied sequencing in the curriculum by introducing the concept of magnetic flux before stating Faraday's law which is regarded as more conceptually effective by the expert CoRe. However, both teachers indicated that they followed the sequencing of the textbook without indicating whether they regarded the textbooks sequencing as more effective that that implied in the curriculum and why.

7.3.3.2 What is difficult to teach?

The majority of the participants adequately interpreted the curriculum with regards to *what is difficult to teach.* They addressed the difficulty alluded to in the curriculum relating to application of the RHR as well as extended it to address difficulties with the concept of magnetic flux by using diagrams to explain the concept.

7.3.3.3 Learners' prior knowledge and misconceptions

For this component, the curriculum was interpreted at face value by the participants. The participants' mostly referred only to prior knowledge in their lessons or post-interviews which related to magnetic fields, emf, and current which are explicitly mentioned in the curriculum. Important concepts, according to the expert CoRe, relating to the topic of Energy which are not discussed in the curriculum were however not referred to by the participants.

7.3.3.4 Representations

The curriculum was mostly enacted inadequately as the majority of the participants did not perform a practical demonstration of Faraday's law as expected by the curriculum. Nevertheless, the participants were aware of the significance of including some form of representation of Faraday's law in their lesson. Except for Tebogo, the other participants did not recognise how using the apparatus listed in the curriculum would better aid conceptual understanding rather than using diagrams or everyday objects such as bottles and pens to represent solenoids and bar magnets respectively. Extensions of the curriculum were however seen as all of the teachers included some form of representations of magnetic flux in their lesson which are not mentioned in the curriculum.

7.3.4 Primary research question: How can selected teachers' enactment of the curriculum on Faraday's law be understood in relation to their reported PCK?

The results of this study have shown similarities and variations between teachers' reported PCK in relation to their interpretation of the curriculum. Where reported PCK was Basic (2), participants interpreted the curriculum mostly at face value whereby few to no extensions of the curriculum were observed. In some cases, participants interpreted the curriculum adequately as a more in-depth interpretation was evident which saw participants extending the curriculum to aid conceptual understanding. In these instances, the participants reported Developing (3) PCK. This indicated that, in most instances, the participating teachers' interpretation of the curriculum aligned with their reported PCK. Misalignments, however, also emerged but they were few.

Regarding *curricular saliency*, Michelle and Tebogo's competences were Developing (3) and they revealed an adequate interpretation of the curriculum. They presented the same key ideas in their lesson as those evident in the curriculum but also extended it by introducing key ideas or sub-ordinate ideas not alluded to in the curriculum. The reported PCK of the teachers matched with their ability to identify key ideas that are alluded to in the curriculum such as 'Magnetic flux' and 'Faraday's law'. Tebogo in particular also referred to the key idea of 'The phenomenon of induction' which is not specified in the curriculum but included in the expert CoRe. Michelle, on the other hand, stated Lenz's law which is not referred to by name in the curriculum. The quality of their reported PCK was also aligned with their ability to interpret the sequencing of ideas in the curriculum and whether it allowed for conceptual understanding. Although Michelle adapted the sequence that is in the curriculum while Tebogo followed it, both teachers' sequencing were considered effective for conceptual understanding. Tebogo in particular adhered to the curriculum after extending it by referring to the phenomenon of induction. He regarded it as necessary to refer to Faraday's law before the concept of magnetic flux to show learners the variables that are necessary in understanding the law, variables that learners observed during his demonstration of induction.

Alignments and misalignments were found in the component of *learners' prior knowledge and misconceptions*. All the participating teachers were allocated a Basic (2) score in that they referred to only a few concepts that constitute prior knowledge, for example magnetic fields. During teaching, Michelle and Linda only referred to the prior knowledge of magnetic fields, while Tebogo and Sarah showed a better interpretation than what their reported PCK suggested. Both teachers' lessons revealed that they were aware of more concepts from prior topics which are important for the understanding of Faraday's law than what they had mentioned in their reported

PCK. It is possible that the teachers did not see the need to specify the necessary pre-concepts when writing the CoRes despite being aware of their place in Faraday's law. The concepts that were absent from Tebogo and Sarah's reported PCK but evident in their lesson related to magnetic field lines and emf which are concepts that are mentioned in the section of Faraday's law in the curriculum.

In terms of *what is difficult to teach*, all the participating teachers' reported PCK was Developing (3). However, only Michelle, Tebogo, and Sarah interpreted the curriculum adequately by extending the curriculum. The teachers addressed difficulties that are not explicit in the teachers' guidelines, a section of the curriculum that indicates the areas that need attention. For example, they pointed out to learners during their lessons which magnetic field the thumb must point in to determine the direction of the induced current, which is not clearly specified in the curriculum. They also used demonstrations and diagrams to address learners' inability to visualise vectors in three dimensions which is also not alluded to in the curriculum. Linda's reported PCK on the other hand revealed knowledge of difficulties relating to the number of new concepts introduced in the topic of Faraday's law. Linda explained that Faraday's law contained many new concepts such as magnetic flux and Lenz's law which added to the difficulty of the topic. Her lesson, however, further exacerbated this very same difficulty she was aware of by introducing more than one topic in the same lesson and thus many new concepts in a short amount of time.

The component of *representations* also revealed alignments and misalignments between curriculum interpretation and reported PCK. Tebogo was the only participant who showed a demonstration of Faraday's law in the form of a video which most closely related to the demonstration and apparatus prescribed in the curriculum. This aligned with his Developing (3) competence for this component in his reported PCK. Michelle's demonstration, however, focused on the direction of the induced current rather than the induced emf. Her demonstration also made use of a bottle and a pen to represent a solenoid and bar magnet which is inappropriate as neither the magnetic field nor the current could be visualised. Linda's representation of Faraday's law using an induction torch was inadequate as learners could not see specific apparatus inside the torch and thus could not make important observations from the demonstration. These teachers' lessons underrepresented the curriculum in terms of the demonstration explicitly prescribed in it. A demonstration or small group investigation of induction is vital in convincing learners that there needs to be relative motion between a magnet and a conducting loop so that they can link the rate of change of flux with Faraday's law. This inadequate interpretation of a demonstration of Faraday's law in the curriculum aligned with their Basic (2) competence of *representations*. Misalignments were, however, seen in the fact that despite their Basic (2) PCK scores for *representations,* Michelle, Sarah, and Linda extended the curriculum by including some form of representation to explain magnetic flux, while they did not include these in their reported PCK. Linda specifically used various diagrams to explain the factors which influence the magnitude of flux as well as how the angle needed to calculate flux is determined.

This study also found that resources such as textbooks and the internet can inflate teachers reported PCK while not necessarily adding to their conceptual understanding. For example, both Michelle and Sarah stated that they introduced magnetic flux before Faraday's law in their lessons because it was the sequencing that appeared in the textbook they used to plan their lessons. Sarah's comments in her post-interview, however, revealed that she was not confident as to which sequencing, between that implied in the curriculum versus the textbook, was more effective. The influence of the textbook on Michelle's reported PCK was also apparent from her admission that she chose to state Lenz's law because it was stated in the textbook she used rather than recognising that Lenz's law is implicitly discussed in the curriculum. Furthermore, Michelle had seen during an internet search that Lenz's law related to pre-concepts from the topic of Energy. However, she did not use this relationship to explain the direction of the induced emf in her lesson, likely due to the fact that she did not properly understand this relationship as revealed in her reported PCK.

Lastly, the results of this study found that while the curriculum contains some information which informs teachers' PCK on Faraday's law, important PCK relevant to the topic such as pre-concepts and misconceptions are not alluded to in the document. In some cases, the information in the curriculum is regarded as undermining its support of teachers' PCK when compared to the PCK in the expert CoRe. This is evident in the curriculum's sequencing of magnetic flux, Faraday's law, and the RHR which is regarded as ineffective for conceptual understanding according to the expert CoRe.

7.4 CONCLUSION

This study has attempted to answer the primary research question of: How can selected teachers' enactment of the curriculum on Faraday's law be understood in relation to their reported PCK? This study revealed that the participating teachers generally have Basic (2) PCK of Faraday's law. As their interpretation of the curriculum mostly aligns with their reported PCK, their Basic (2) competence in a particular component resulted in a face value interpretation of the curriculum and thus failing to recognise shortcomings in the document which call for adaptions or extensions of its contents. Furthermore, Developing (3) PCK predominantly placed the participating teachers in a better position to interpret the curriculum adequately and recognise shortcoming in the curriculum which require extensions for effective teaching. This is particularly important given the fact that the curriculum appears to be a framework showing what to teach without sufficient information on how to teach the concepts. For example, teachers with Developing (3) PCK were able to identify key ideas while being mindful of the sequencing of concepts in the curriculum and whether adaptions of the sequence were necessary in order to support conceptual understanding, which is the foundation of PCK (Shulman, 1986). Similarly, they were also able to refer to pre-concepts that are scheduled earlier in the curriculum which they integrated in the new knowledge, for example magnetism and current. In terms of *representations*, participants with Developing (3) PCK such as Tebogo were able to recognise the importance of demonstrations prescribed in the curriculum and the specific observations that learners should make from them. Furthermore, a greater level of reported PCK allowed participants to extend the curriculum by addressing difficulties beyond that which are alluded to in the teacher guidelines. It can therefore be concluded that a teacher's interpretation of the curriculum can be attributed to their reported PCK. It was also found that their interpretation the curriculum as to the curriculum's expectations or shortcoming was enhanced in instances where their reported PCK is more developed. Cases, however, were also evident in which a misalignment between participants' interpretation of the curriculum and reported PCK occurred such as reporting poorer PCK of important pre-concepts than what was evident in their lessons. This indicated that Basic (2) reported PCK would not necessarily limit a teacher's interpretation the curriculum in every instance.

7.5 LIMITATIONS AND RECOMMENDATIONS

7.5.1 Limitations of this Study

Loughran et al. (2004) acknowledged teachers' struggle to articulate their professional knowledge such as their PCK. CoRes are used to capture a teacher's PCK thus making what is tacit explicit. However, none of the participants in this study had seen or completed a CoRe before which possibly made completing them an intimidating task. The teachers were also not remunerated for their participation in this study and so they may not have put much effort into completing the CoRes. As a result, the CoRes were poorly answered with brief explanations provided and many spaces left blank. Pre-interviews were used to supplement the data collected in the CoRes which helped gain further insight into the participants' PCK. The data captured in the CoRes and pre-interviews still cannot be regarded as a complete representation of the participants' PCK within the topic of Faraday's law as PCK is inherently difficult to capture as it is tacit knowledge (Loughran et al., 2004).

Another limitation of this study is that there was a small sample as for a case study, with only four participants who were selected through convenience sampling. The participants all taught at well-resourced schools in Tshwane. This bias of under representation or over representation is acknowledged and also limits the generalisations which can be made from this study. The findings of this study are also limited to the topic of Faraday's law. However, the results are not meant to be generalised. Instead, a case study seeks in-depth understanding, which was achieved in this study.

7.5.2 Recommendations for Future Research

Faraday's law has been found to be a difficult topic for learners (Román, 2012; Zuza et al., 2014). The absence of important pre-concepts from the topic of Energy, misconceptions, and the sequencing of some content of the curriculum further limits the extent to which the document is able to support teachers' PCK on a particular topic.

Although the results of this study revealed that teachers' interpretation of the curriculum can be attributed to their reported PCK, for teachers with little PCK, the textbook often becomes the primary source of information from which they draw to plan their lessons. Thus, teachers' interpretation of the curriculum cannot always be attributed to their level of reported PCK, but rather, is a reflection of the textbook they used to plan their lesson. As much as textbooks are written by authors with the intent of aiding conceptual understanding, the author's level of reported PCK reflected in the contents of the textbook may not always necessarily be Exemplary (4) based on the reported PCK rubric. It is recommended that further research is conducted to investigate the PCK reflected in the textbooks, the impact of textbooks on teachers' PCK, and their interpretation of curricula.

7.5.3 Recommendations for Future Practice

This study revealed that these teachers have generally Basic (2) PCK of Faraday's law. As their interpretation of the curriculum mostly aligns with their reported PCK, their Basic (2) competence in a particular component resulted in their interpretation of the curriculum failing to recognise shortcomings in the document which call for adaptions or extensions of its contents. In particular, the curriculum provides little guidance on misconceptions and difficulties related to Faraday's law. This leaves teachers drawing on their own experiences during their apprenticeship of observation as learners (Borg, 2004) or their knowledge from prior teaching experience. This places a novice teacher, who has not had the opportunity to develop their PCK from years of teaching, at a disadvantage. The following recommendations are thus suggested for the future:

- The Guidelines for Teachers section of the curriculum should be expanded to include common difficulties and misconceptions documented in the literature.
- Pre-service teacher training as well as in-service teacher development should focus on each component of TSPCK that should be considered when designing lessons.
- Pre-service teacher training should emphasise curriculum interpretation and analysis through the components of TSPCK.

- Textbook writers, especially those of teacher guides, should point out when the sequencing of concepts in their textbooks differs from that of the curriculum and how this sequencing will benefit conceptual understanding of the topic.

This study has shown that there is a positive relationship between the quality of teachers' reported PCK and their interpretation of the curriculum. The knowledge gained from this study can help improve both pre-service and in-service teaching training programmes. This will aid in producing teachers that are able to plan more effective lessons which will allow learners to gain a greater conceptual understanding of difficult topics and concepts in Physical Sciences, a subject that is of critical importance in the South African context.

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APPENDICES

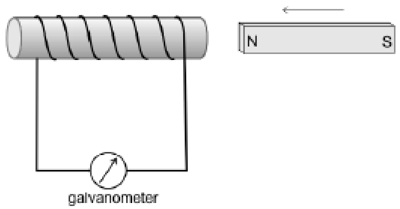
Appendix I: Content Representation tool completed by the researcher and experts: expert CoRe

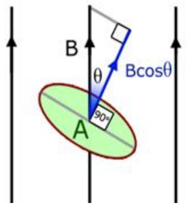
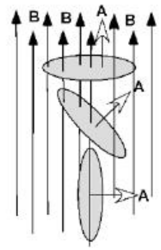
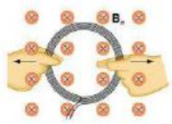
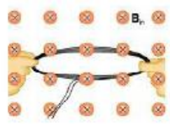
	Key Idea A: **The phenomenon of induction – the basic principle**	**Key Idea B:** **Magnetic flux is the total magnetic field over an area perpendicular to the field**	**Key Idea C:** **Electromagnetic induction – Faraday's law**
A1. What do you intend learners to learn about each key idea?	EA1. When moving a magnet and a conductor relative to one another, a current will be induced in the conductor. EA2. Mechanical energy is converted to electrical energy.	EB1. Magnetic flux through a surface can be thought of as the number of magnetic field lines passing through that surface. EB2. Mathematical definition: $\phi = BAcos\theta$, where ϕ is the magnetic flux measured in weber, **B** is the magnetic field measured in tesla, **A** is the area vector perpendicular to the surface and θ is the angle between **A** and **B**. The area is often the cross-section of a coil. EB3. Ways to change the magnetic flux through a coil.	EC1. Changing the magnetic flux (in any possible way) through a coil will result in induced current. EC2. The magnitude of the induced current depends on: The rate of change in the magnetic flux ($\Delta\phi/\Delta t$) and the number of turns in the coil (N). EC3. Faradays law: $\varepsilon = -N/\Delta\phi\Delta t$ o The meaning of the negative sign EC4. Lenz's law to determine the direction of the induced current. EC5. The relationship between the induced emf (ε) and the induced current is given by $\varepsilon = IR$ where R is the total resistance in the circuit where the current is induced. EC6. Changing the direction of the current in the loop – generating alternating current.

A2. Why is it important for learners to know this key idea?	EA3. To be able to understand the necessity of developing the concept of flux as the way a magnets interacts with a conductor.	EB4. This idea forms the basis of Faraday's law where the rate of change of magnetic flux is an important concept.	EC7. The concept has a practical application in the principle on which a generator operates. Generators form part of the Gr 12 curriculum. EC8. To understand how AC current and DC currents are generated. EC9. To understand the way transformers work.
A3. What else do you know about each key idea (that learners do not know yet?)	EA4. The definition of magnetic flux. EA5. Faraday's law EA6. Lenz's law	EB5. How the rate of change in magnetic flux relates to the magnitude of the induced emf. (This will be dealt with when the next key idea is explained).	EC10. How the idea of electromagnetic induction is applied in transformers and generators.
C1. What are the difficulties/limitations connected with the teaching of this idea?	EA7. The idea of induction is new to learners and it may take a while for them to grasp this fundamental concept.	EB6. Learners have no experience or prior knowledge about the idea of magnetic flux and have not formed misconceptions about the concept. EB7. Learners do not understand how a surface area can be described by a vector. EB8. Learners' ability to visualise the vectors and angles in 3D is limited hence the inability to understand the relevance of or to determine the angles between the magnetic field and the area vector. This specifically impacts their ability to determine the angle needed to calculate magnetic flux.	EC11. Learners think of magnetic field lines as moving entities ("-it goes from north to south"), therefore they think that the mere existence of a magnetic field in a coil will result in induced current. EC12. Learners find it difficult to apply Lenz's law and the right-hand rule to determine the direction of the induced current. EC13. The directions of the induced current and induced field and how they depend on the direction of the flux and whether it is increasing or decreasing.

B1. What is your knowledge about the learners' thinking that influences your teaching of these ideas?	EA8. Magnetic field lines are imaginary lines that help one to visualise the direction and strength of the magnetic field. EA9. Learners' must already have been taught about mechanical and electrical energy. EA10. Learners' must already know about the concepts of current and emf. EA11. Learners believe that current will only be induced when the magnet moves and the loop is stationary.	EB9. Magnetic field and magnetic field lines. EB10. Magnetic field lines are imaginary lines that help one to visualise the direction and strength of the magnetic field. EB11. The vector (**A**) is perpendicular to a surface and indicates the magnitude of the area of the surface and the orientation of the surface. EB12. They may not understand that magnetic field lines are just an imaginary pictorial aid to understand magnetic field, but magnetic flux is an actual physical quantity. EB13. Learners have not encountered the concept of magnetic flux previously and they have not formed misconceptions about the concept.	EC14. Learners tend to think of magnetic field lines as something that moves in a certain direction, indicated by the arrows in the field. Therefore they think that a current will be induced even when the magnetic flux through a loop does not change, reasoning that the current will be induced in a direction so as to oppose the "motion" of the magnetic field lines. EC15. The concept of magnetic flux EC16. Different ways in which the magnetic flux can change EC17. Mechanical energy is converted into electrical energy EC18. The Right-Hand Rule from the topic of Electromagnetism EC19. The concepts of current and emf EC20. Concept of induction EC21. The relationship V=IR
A4. Are there any other factors that influence you teaching of these ideas?			

What are your teaching procedures (and particular reasons for using these to engage with this idea)?	EA12. Connect a coil to a galvanometer. Draw the learners' attention to the fact That there is no source of emf in the circuit. EA13. Take a strong bar magnet and let a learner push it into the coil. Ask the learners about their observation regarding the galvanometer. Emphasise that current is only detected by the galvanometer when the magnet is moving (or when the coil is moving) and that the direction of the current changes when the magnet is pulled out or when the poles are reversed. EA14. Perform actual demonstrations or use computer simulations such as PhET simulations showing how current is induced when there is relative motion between a magnet and a coil.	EB14. Use a piece of cardboard (which depicts a particular surface) and a pencil perpendicular to the surface to explain the A-vector. EB15. Make a loop with a thick wire. Use the light from a light source as an analogy of magnetic flux through the loop. EB16. Explain how the flux changes as the orientation of the loop changes. EB17. Use diagrams to explain the angle between the magnetic field and the area vector. EB18. Use computer simulations such as PhET simulations.	EC22. Ask learners to think of ways in which the magnitude of the current can be increased. Let them test their ideas with the bar magnet and the coil. EC23. Introduce learners to the following words and phrases and relate them to the demonstrations above: o A change in magnetic flux induces current in the coil. o If the rate of change in magnetic flux is higher (the magnets move faster), the magnitude of the induced current is higher. o The direction of the induced current depends on the direction of the flux and whether it is increasing or decreasing. o Lenz's law EC24. Introduce the learners to Faradays' law and relate the meanings of the symbols to the demonstrations above. EC25. Work through example problems.

Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses)	EA15. Use a representation with actual apparatus to show a coil connected to a galvanometer and a strong bar magnet. EA16. Ask what is required to induce current in a coil (without a power source). EA17. Ask the following questions: - When connecting a coil to a galvanometer, ask: What is the function of the galvanometer? - What happens when the magnet is moved relative to the coil? How is it possible for the magnet to interact with the conductor without touching it? - Which energy conversion is taking place in this situation?	EB19. Give diagrams of loops or coils where a magnetic field exists. The diagrams will show different orientations of the area of the loop and the direction of the magnetic field. Ask learners to calculate the flux. EB20. Ask learners to calculate the change in flux $\Delta\phi$, when **A**, **B** or θ changes. EB21. Before suggesting ways to change the magnetic flux, ask learners to think of ways in which the magnetic flux can be changed. EB22. When rotating the loop, changing its orientation relative to the flux, ask: o When is ϕ=0? EB23. When is ϕ a maximum/a minimum? EB24. When is the *rate of change* of flux a maximum/ a minimum?	EC26. Ask learners to predict the direction of induced current when given diagrams of coils or loops, with the change in magnetic flux indicated. EC27. Learners must solve unseen problems. EC28. When doing the demonstration with the coil and bar magnet, ask: o Is there current in the coil when the magnet is not moving? o How can one increase the amount of current in the coil? – Move the magnet faster, use a stronger magnet, use a coil with more turns. o How can one change the direction of the current induced in the oil? – Pulling the magnet out of the coil; reversing the poles of the magnet when pushing it into the coil EC29. Relate the energy conversion to the conservation of energy and the direction of the induced current and induced field. EC30. Actual demonstrations or computer simulations can be shown. EC31. Right-hand rule to determine the direction of induced current. EC32. Diagrams such as: 

		EB25. A cardboard and pencil to explain the area vector and its orientation. EB26. A wire loop and light source. EB27. Diagrams:    	

Appendix II: The CoRe rubric for the scoring of the teachers' reported PCK

	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Curricular saliency	• Identified irrelevant key ideas / pre-concepts as key ideas. • Illogical sequencing of concepts due to inadequate key ideas. • Indication of the interrelatedness of the concepts is missing. • The importance of concepts is missing.	• Identified few relevant key ideas and subordinate ideas with pre-concepts included. • Sequencing has an illogical placing of key ideas. • Indication of the interrelatedness between concepts is clumsy due to the illogical placing of a key idea. • Pre-concepts are mixed with key ideas. • Reasons for the importance of concepts exclude scaffolding into subsequent topics.	• Identified some relevant key ideas. • Key ideas are sequenced logically. • Identified supporting subordinate ideas. • Some indication of the interrelatedness includes scaffolding between concepts. • Subsequent related topics are not specified.	• Identified many key ideas. • Concepts are logically sequenced. • Identified subordinate ideas and showed links with key ideas. • The indication of the interrelatedness amongst concepts is adequate. • Reasons for the importance of concepts includes scaffolding and the subsequent topics are specified.
Learners' prior knowledge and misconceptions	• No identification / acknowledgement of learners' prior knowledge or misconceptions.	• Identified little prior knowledge/knowledge needed for the understanding of the topic. • Identified few major misconception and other minor misunderstandings. • Identified basic learner errors related to the mathematical concepts	• Identified prior knowledge/pre-concepts needed for the understanding of the topic but not how it influences the teaching of the topic. • Identified some major misconceptions and other minor misconceptions.	• Identified prior knowledge/pre-concepts pertinent to the understanding of the topic and how they influence the teaching of the topic. • Identified many major misconceptions and other minor misunderstandings.

		without linking it to science concepts.		
What is difficult to teach	• No indication of concepts/ideas that are difficult to teach. • Reasons for the difficulty or gate-keeping concept are not specified.	• Identified broad concepts as difficult. Reasons for the difficulties are not specific to the key ideas. e.g. "their science knowledge is poor".	• Identified specific concepts as difficult. • Outlined reasons related to learners' common difficulties.	• Identified specific concepts as difficult. • Outlined gate-keeping concepts as well as the reasons for these difficulties or misconceptions that perpetuate them.
Conceptual teaching strategies	• No strategy to expose learners' difficulties and misconceptions. • No strategy to confront and address misconceptions and difficulties. • No indication of how key ideas will be explained. • No intentions to involve representations to engage with learners. • Overall highly teacher centred lessons.	• Evidence of activities to expose learner misconceptions and difficulties. • Verbal confrontation of misconceptions and difficulties. • Indication of how some key ideas will be explained without an explanation of the interrelatedness. • Representations outlined but concepts to be supported are absent. • Limited involvement of learners.	• Evidence of activities to expose learners' misconceptions and difficulties. • Confrontations of difficulties and misconceptions evident. • Indication of how some key ideas will be explained and interrelated. • Representations identified to explain concepts in general. • There is evidence of learner involvement.	• Evidence of activities to expose learner misconceptions and difficulties. • Confrontation addresses gate-keeping concepts (misconceptions) beforehand. • Indication of how all key ideas will be explained and interrelated. • Representations to be used to explain concepts in general and the ones identified as difficult. • Highly learner centred.
Representations	• Representations not identified.	• Identified a few relevant representations. • No information about how the representations works and which concept they support.	• Identified some relevant representations. • Outlined how the representations supports the explanations of concepts.	• Identified many relevant representations. • Outlined how the representations support the confrontation of misconceptions and difficult concepts.

Appendix III: Content representation tool completed by the participants

Content Representation tool (CoRe) Participant: Tebogo

School: 1

1. Please fill in the key ideas on Faraday's Law	
Key idea A Understanding the electromagnetic induction.	Key idea B Magnetic flux
Key idea C Calculations of emf	Key idea D

2. What do you intend learners to learn about each key idea?	
Key idea A - Understand how the ~~efemf~~ emf is induced. - How to increase the induced emf.	Key idea B - What a magnetic flux is, and - How it can be calculated.
Key idea C Understanding how to Calculate the emf with the changing - flux - field - Area - Time.	Key idea D

3. Why is it important for learners to know this key idea?	
Key idea A - It will help them understand how electricity is generated. -	Key idea B - It will help them to link the magnitic field and magnetic flux
Key idea C key skill in Physical Science is linking the theory and Calculations which help learners understand better	Key idea D

4. What else do you know about each key idea (that you do not intend learners to know yet)?	
Key idea A - Electomagnetic induction is used in transformers. - A C & DC that use electromagnetic induction	Key idea B - FARADAY's first & Second Laws.
Key idea C	Key idea D

5. What are the difficulties/limitations connected with teaching this idea?	
Key idea A - Learners always confuse magnetic field & flux -	Key idea B Learners always struggle to ~~ed~~ determine the change in flux.
Key idea C - The angles associated with the formula $\Phi = B.A\cos\theta$.	Key idea D

7. Are there any other factors that influence your teaching of this ideas?	
Key idea A - There should be resource to help learners view the difference between flux and field.	Key idea B - The magnetic flux and the change there of should be fully explained, ~~to~~ as it might make it difficult for the learner to understand the induction of the electromagnet.
Key idea C	Key idea D

6. What is your knowledge about the learners' thinking that influences your teaching of these ideas?	
Key idea A - They don't like the theory, they just want to calculate. - They never thought a magnetic field would have quantity (magnitude)	Key idea B - To them, flux should always be ZERO.
Key idea C - The dont expect to calculate anything other than the emf.	Key idea D

8. What are your teaching procedures (and particular reasons for using these to engage with this idea)?	
Key idea A - Revise what a magnetic field is - Learners should understand the difference between the: • Current carrying conductor • Selenoid.	Key idea B • magnetic flux is through the surface, and ~~this~~ there is an angle between the normal of the surface and the magnetic field.
Key idea C - Learners should start how to calculate the • magnetic flux • ~~magne~~ change in magnetic flux • emf In that order.	Key idea D

9. Specify ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).	
Key idea A - By using different resource where they could see what a magnetic field is, and how we use it to determine the flux.	Key idea B
Key idea C	Key idea D

Content Representation tool (CoRe) Participant: Michelle

School: 1

1. Please fill in the key ideas on Faraday's Law

Key idea A	Key idea B
Change in magnetic field	Induced emf
Key idea C	**Key idea D**
Magnetic flux	Induced current.

2. What do you intend learners to learn about each key idea?

Key idea A	Key idea B
How a magnetic field can be changed: - magnet moved into a solenoid - magnet moved out of solenoid - solenoid moved across magnet	Emf may be generated by a change in the magnetic environment. Emf magnitude determined by - strength of magnet - number of windings - rate of relative movement.
Key idea C Definition of magnetic flux	**Key idea D**
Change in magnetic flux: $\Delta\phi = \Phi_f - \Phi_i$ Rate of magnetic flux: Rate of $\Delta\phi = \frac{\Delta\Phi}{\Delta t}$	Induced current will create an induced magnetic field which will oppose the change in magnetic flux → Lenz's law → RHR.

3. Why is it important for learners to know this key idea?

Key idea A	Key idea B
To understand the relevance and results a changing magnetic field will have on the emf generated.	To be able to understand how emf is generated in a condutor as well as to be able to understand and use Faraday's law and formula.
Key idea C	**Key idea D**
To understand how magnetic flux fits into Faraday's Law and the relationship between the emf and the rate of change of magnetic flux.	To be able to understand that the induced current flows in such a direction so that the magnetic field generated by the conductor will always oppose the change in magnetic flux.

4. What else do you know about each key idea (that you do not intend learners to know yet)?

Key idea A	Key idea B
Key idea C	**Key idea D**
	Change in magnetic flux means changes in energy. In other words: Lenz's Law is an idea of conservation of charge.

5. What are the difficulties/limitations connected with teaching this idea?

Key idea A	Key idea B

Key idea C	Key idea D
	Learners struggle to understand the fact that the magnetic flux is being resisted.

7. Are there any other factors that influence your teaching of this ideas?

Key idea A	Key idea B
I am a first year teacher I haven't taugh this topic. I think that is a major influence on how comfortable and known I am with the work and how to explain	it so that the learners can understand it to the best of their ability

Key idea C	Key idea D

6. What is your knowledge about the learners' thinking that influences your teaching of these ideas?

Key idea A	Key idea B
Learners struggle to underständ the concepts because it can't be seen with the bare eye. Last year in gr 10 they only touched magnetism and	electrostatics a bit. Not in depth at all. They usually understand the concepts better if they can see what is happening and relate to the concepts.

Key idea C	Key idea D

8. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key idea A	Key idea B
→ Preparing → Recap, ask learners questions on previous work to see what they remember and what not.	→ Start with the new work, explain what it is about. and teach them an intro → In this case I started with the magnetic fields around a straight carrying conductor, coil and solenoid → I draw all the different ones on the board and explained the RHR.

Key idea C	Key idea D
→ After wards I explained how electromagnetism is used in our daily life so they get a clear picture → Then I started explaining Electromagnetic induction, magnetic flux with help of notes and drawing the scenarios on the board	Then I explained faraday's Law through definitions / formula and drawings. Lastly I explained Lenz's Law drawing the 4 different scenario's on the board.

9. Specify ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).	
Key idea A → Make use of a lot of media like pictures, video's explaining it so learners can actually see what is happening	Key idea B → Make use of experiments For e.g as a intro show them how to make an electromagnet.
Key idea C	Key idea D

Content Representation tool (CoRe) Participant: Sarah

School: 2

1. Please fill in the key ideas on Faraday's Law

Key idea A	Key idea B
Magnetic fields	Magnetic flux.
Key idea C	**Key idea D**

2. What do you intend learners to learn about each key idea?

Key idea A	Key idea B
• Always have North pole & South pole. • Magnetic field lines exist around magnets.	• It is the amount of magnetic field lines ⊥ to area of coil of conductor. • Change in magnetic flux can induce current (emf). • Can also change because of change in magnetic field strength
Key idea C	**Key idea D**

3. Why is it important for learners to know this key idea?

Key idea A	Key idea B
They must understand the ~~shape~~ magnetic field lines (as imaginary lines) to understand how a coil can move through it.	Faraday's Law is based on change in magnetic flux. If they don't understand the term magnetic flux they won't understand how it can create an emf (current)
Key idea C	**Key idea D**

4. What else do you know about each key idea (that you do not intend learners to know yet)?

Key idea A	Key idea B
	It is the basis for the working of motors and generators (Gr. 12 work).
Key idea C	**Key idea D**

5. What are the difficulties/limitations connected with teaching this idea?

Key idea A	Key idea B
Because it is imaginary lines some learners might find it difficult to imagine.	It is only a change in magnetic flux that can create a current.
Key idea C	**Key idea D**

6. What is your knowledge about the learners' thinking that influences your teaching of these ideas?

Key idea A	Key idea B
Learners needs to see where these topics are used in everyday life for them to understand it beter. So it is always necessary to use real life examples.	
Key idea C	**Key idea D**

7. Are there any other factors that influence your teaching of this ideas?

Key idea A	Key idea B
	My limited knowledge influence my teaching. I have to prepare a lot more and watch videos.
Key idea C	**Key idea D**

8. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key idea A	Key idea B
	I like to show video's with simulations, so that the learners can see how things change,
Key idea C	**Key idea D**

9. Specify ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).	
Key idea A	Key idea B Doing some extra exercises on this topic to first make sure whether they understand or not Learners doing the extra exercises will benefit from it.
Key idea C	Key idea D

Content Representation tool (CoRe) Participant: Linda

School: 2

1. Please fill in the key ideas on Faraday's Law

Key idea A	Key idea B
The magnetic effect of current	Effect of magnetic field on current

Key idea C	Key idea D
Magnetic flux	Induced EMF

2. What do you intend learners to learn about each key idea?

Key idea A	Key idea B
The right hand rule	Magnetic field vs electric field

Key idea C	Key idea D
Magnetic flux vs magnetic flux density	Faraday's law in words and symbols.

3. Why is it important for learners to know this key idea?

Key idea A	Key idea B
To understand relationship between electricity and magnetism. Introduces idea B. →	

Key idea C	Key idea D
They have to understand magnetic flux before they can understand change in flux	Induction is needed to understand how motors and generators work in grade 12.

4. What else do you know about each key idea (that you do not intend learners to know yet)?

Key idea A	Key idea B
Shape of field through a coil or solenoid	Flemming's left hand and right hand motor rule. Lenz's law

Key idea C	Key idea D
//	//

5. What are the difficulties/limitations connected with teaching this idea?

Key idea A	Key idea B
Abstract ideas. Not visible to learners Need to find visual/3D representation of ideas.	
Key idea C	**Key idea D**

7. Are there any other factors that influence your teaching of this ideas?

Key idea A	Key idea B
Key idea C	**Key idea D**
	Learners have to do calculations and must be able to interpret questions.

6. What is your knowledge about the learners' thinking that influences your teaching of these ideas?

Key idea A	Key idea B
They have very little background about these ideas. Magnetism and electricity has been treated as two seperate fields up to now.	
Key idea C	**Key idea D**

8. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key idea A	Key idea B
	YouTube video of effect of magnetic field on a conductor. If they don't see it, they will not understand. Difficult to reproduce in class
Key idea C	**Key idea D**
I use various diagrams to build up the idea of magnetic flux and change in flux	Demonstrate with a torch that uses induction.

9. Specify ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).	
Key idea A	Key idea B
Key idea C	Key idea D Are they able to solve problems independantly?

Appendix IV: Participants' transcribed pre-interviews

MICHELLE - PRE-INTERVIEW (SCHOOL 1)	
Jared	***I would just like to know, what so far have you introduced with regards to the topic of Faraday's Law to your learners?***
Teacher	I started with the Electromagnetism, then I started with explaining the three different types of conductors, the straight, the coil and the solenoid. After that, I went through the implications of Electromagnets in your daily lives and the impact that it has on a person. Then I started with magnetic flux and how you calculate it and the change in magnetic flux. And that's where I ended the previous lesson. Now I'm going to start with Faraday's Law and Lenz's Law. That's it.
Jared	***So you've identified in Faraday's Law four key ideas. In which order would you sequence these key ideas in order to teach them?***
Teacher	The first one will be the change in magnetic field so they understand you have to make a change in the magnetic field for EMF to be induced. And then after that I will do the magnetic flux and the rate that the magnetic flux changes to help them understand how it fits into Faraday's Law. Then the induced EMF through the formula they gave us and what influences the induced EMF. And then afterwards I will do induced currents, just the direction using the right-hand rule using Lenz's Law as well.
Jared	**Alright, what made you select these specific key ideas?**
Teacher	I looked at the definition for Faraday's Law and then I identified all the concepts, all the ideas, using the definition and what will influence the definition, or what has an influence on Faraday's Law.
Jared	**We're going to take each key idea and ask you questions based on that key idea. So for change in magnetic flux, what do you intend for learners to learn about this idea?**
Teacher	Ok so how to calculate it with the formula with the final magnetic flux and the initial and explain to them on the board how you measure the final and the initial and then also the definition for magnetic flux, that it's the number of field lines and how does it have an influence on Faraday's Law. So the magnetic flux, the rate and stuff like that.
Jared	**Alright so then you've also spoken about magnetic flux and what you intend for learners to know about the induced EMF?**
Teacher	Yes.
Jared	**What do you intend for learners to know about that?**
Teacher	Ok so how to calculate it using the formula given to us and what will influence it, like the number of windings, the strength of the magnet, etcetera.
Jared	**Just lastly, what do you intend learners to learn about induced current?**
Teacher	In the textbook they say a change in magnetic field can cause an induced EMF and an induced current but they don't really say anything else. They just teach them the direction so using the right hand rule, I will teach them in what direction the induced current is flowing around the solenoid.

Jared	**Alright. I would just like to ask you what is magnetic flux? What do you see as magnetic flux?**
Teacher	The textbook defined it as the formula but then I did a bit of research and they say it's the number of magnetic field lines moving through an area so that's how I explain it to the learners as well.
Jared	**I see on the first page you have given the formula for the change in magnetic flux. What is just flux's formula?**
Teacher	Just flux's formula is the delta or the weber sign, what do you call the sign?
Jared	**The unit?**
Teacher	Yes.
Jared	**Weber.**
Teacher	Weber equals "B" times "A" cosTheta.
Jared	**Why do you feel it is important for learners to know about change in magnetic field?**
Teacher	I think it's because it has everything to do with Faraday's Law. If there's no change in magnetic field, there's not going to be an induced EMF and there's not going to be an induced current as well.
Jared	**Why is it important for them to know about magnetic flux?**
Teacher	Because in Faraday's Law, the second part is the change in magnetic flux or the rate of magnetic flux. So I think they have to understand what magnetic flux is, how you can calculate the change in magnetic flux and how do you calculate the rate of magnetic flux.
Jared	**In general, why do learners get taught about Faraday's Law?**
Teacher	*Ek weet nie* (I don't know). To understand electromagnetism.
Jared	**What else do you know about the key idea Change in magnetic field that you feel learners do not know yet?**
Teacher	Nothing.
Jared	**Is there anything with induced EMF or magnetic flux, your key ideas B and C that you feel you may know something about it but your learners do not yet?**
Teacher	No.
Jared	**And for the induced current?**
Teacher	Yes, the change in magnetic flux means change in energy. *Ek het daai gaan Google* (I went and Googled that).
Jared	**Does the topic Faraday's Law relate to any other topics in the curriculum of let's say grade 10, 11 or 12?**
Teacher	In grade 10 they just touched on to electrostatics and magnetism but not electromagnetism really so it was separate units and now it's combined and that's all they did in grade 10.

Jared	**What are the difficulties or limitations connected with the idea of a change in magnetic field? What difficulties may learners have?**
Teacher	I think because they can't see it with their bare eyes, they struggle to understand how it works, that's why I think it's very necessary to show them videos and images and stuff so they can understand it and not just think about it but actually see it in front of them with their eyes.
Jared	**And just the same idea, what difficulties or limitations could learners have with the idea of magnetic flux?**
Teacher	I think the same because they can't see the magnetic field lines going through the area of the conductor so they don't understand how it works. So with all of these, I think it's important to show all the videos and examples, do practical examples in class if there's time for them to understand the concepts better.
Jared	**You say you have already introduced the concept of magnetic flux?**
Teacher	Yes.
Jared	**Were there any representations or pictures or videos or anything along those lines that you used?**
Teacher	I used the projector to draw on the board the three different ones where it's parallel to the area, perpendicular to the area, and at an angle. So I explained that to them using the overhead projector and gave them an example of each other and the different cases that you can get.
Jared	**What difficulties could learners have with the idea of induced current?**
Teacher	So I think that they will struggle with the idea of with the magnetic field opposing the change in magnetic flux. So the direction because of the north and the south pole will be closer, they struggle to distinguish which north pole to place your thumb in.
Jared	**What is your knowledge of the learners thinking that influences your teaching of change in magnetic field? So what is your knowledge about how learners may think about this idea that influences the way that you will teach it?**
Teacher	I think that you have to think the same as them and use a lot of different examples to show them how it works because if you just read through the content, you're not going to understand. So make use of a lot of pictures and videos and examples. They do some building of an electromagnetic in class so they understand better and relate to the concept but not just see it in their textbook.
Jared	**For any of your other key ideas, is there anything else that you would like to add about what is your knowledge about learners' thinking of that key idea that influences how you will teach it?**
Teacher	No.
Jared	**Are there any other factors that influence the teaching of your key ideas?**
Teacher	*Kan ek se die feit dat ek 'n eerste jaar onderwyser is?* (Can I say the fact that I'm a first year teacher?)
Jared	**That's fine.**

Teacher	The fact that I'm a first year teacher. We didn't even do this in university. They skipped this whole part so it's not in my textbooks.
Jared	**This whole part as in electromagnetism?**
Teacher	Like we didn't do Faraday's Law, we didn't do Lenz's Law. So we didn't do practical in it so that's why I am not really known with the content. So I had to study it.
Jared	**Did you study anything with regards to magnetism at university?**
Teacher	We did obvious examples like north and south and how do you do the experiment with magnets and magnetic field lines and iron filings but just simple grade 9 examples, not in-depth.
Jared	**And circuits?**
Teacher	No, not circuits at all so I'm bad at circuits as well.
Jared	**What are your teaching procedures and particular reasons for using this to engage with learners?**
Teacher	Ok so I identified the key teaching ideas first and started with the easy stuff like electromagnets, where we use them and where you can find them in your daily life as well as the three different types of conductors as well as explained to the learners how to use the right hand rule so that they can get used to it. After that I moved on to magnetic flux and explained that. Did a few examples on magnetic flux. How to calculate the difference in magnetic flux and then moved on. I also draw the three different cases on the board, explained it to them, [and] did examples on that. Planned to teach Faraday's Law starting with the definition. And then doing an example on the formula and tell them as well what will influence Faraday's Law. Then after that, Lenz's Law to explain to them how to calculate the induced current. After that I will give them an activity so they can get used to calculating the induced EMF and the direction of the induced current.
Jared	**The last question, specify ways of ascertaining learners understanding or confusion surrounding this idea. Include a likely range of responses learners may give. So how would you determine whether a learners understands the key idea of a change in magnetic field?**
Teacher	So at the beginning when I started, I saw that they didn't really understand, so I started showing them a video on how you can build an electromagnet and how the magnetic field can change when you move it towards the solenoid or away from the solenoid. And then they understood better. Same with the other concepts, I drew them the different cases on the board.
Jared	**What cases are those?**
Teacher	The ones say whether the magnetic flux are parallel to the areas, perpendicular to the area or at an angle to the area.
Jared	**With your answer in the CoRe document, you said you will recap. Can you just explain again?**

Teacher	So the previous day I taught magnetic fields and the different types of conductors and the next day I will recap and ask them 'Can you remember what the different types of conductors?' and then 'How does it relate to Faraday's Law with the rate of flux?'
Jared	**In your lessons for teaching Faraday's Law, will you use any demos, simulations, apparatus, representations, diagrams, anything along those lines?**
Teacher	My planning just consists of giving them the definition, doing an example on the board, drawing an example on the board as well as to explain the induced current. I have a bottle to explain for example the solenoid and explain the right hand rule using the bottle. Then if they do not understand I will carry on explaining it with a video or send a video link on the group or photos for them to understand better. And the solenoid or Lenz's Law, I have the four different cases where the north pole moves into the solenoid first, then the south pole and then when you pull out the magnet as well so I will draw that on the board using the overhead projector.

TEBOGO - PRE-INTERVIEW (SCHOOL 1)	
Jared	**You identify three key ideas towards understanding Faraday's law. A as understanding the electromagnetic induction, B – magnetic flux, and C – calculations involving emf. In what order would order would you introduce these concepts to learners?**
Teacher	I will start first with what the electromagnetic induction is because for me it leads to them understanding the flux. Because for us to calculate the flux, we need to know what the magnetic field is and then we need that to calculate the emf. So the learners first understand why we need electromagnetism in our lives. And then break it down to the flux, what the flux is and then how is that related to the calculation.
Jared	**For the question of: What do you intend for learners to learn about each key idea. If you could maybe just expand on understanding electromagnetic induction what would you like them to know about this concept?**
Teacher	Remember learners need to first link the topics we do in class with the outside world. I normally used to tell them, 'OK tell me how is electricity produced?'. They all tell you until where electricity is produced but they don't tell you what the generator does which is actually important which is where we have the electromagnetic induction. So we start first there so that learners first understand that we didn't just create electricity like we made magic and it came to be. Where did it all start? And then we also need to tell them, why did we need to teach you magnets is grade 10, how are they related to electricity that we are doing now? So for me, I needed to link first the learners', the grade 10 knowledge of magnets and electricity to electricity production in South Africa or the world. To make them understand that for us to produce that electricity, there must be electromagnetic induction is being induced.
Jared	**Alright, and then for key idea B – magnetic flux, what would you like your learners to learn about this key idea?**
Teacher	Remember we produce and then we have the calculations of the electromagnetic induction that is being induced. A learner first has to understand what electromagnetic induction is, what the flux is and what the field is. So for me to teach that idea, it somehow makes me to link the calculation and the theory. That for us to be able to start to say that we have the electromagnet that was induced, there was a flux, there was a field and before we had the field we had the area that had the non-contact force if I can put it that way. So I like to have a small map of where we are starting and where we are ending. And the flux is in the middle.
Jared	**What do you intend for learners to learn about your key idea C of calculations of emf?**
Teacher	There are too many…you know the type of learner that we have now-a-days is the learner that is lazy. They are lazy to think. As teachers somehow we have to think for them, that's what I've seen. So a learner will only cram one way of calculating the emf not knowing that the angle can change, the field can change and also the area can

	change. They will only stick to one formula that I need to get the flux using this equation and then I get that change in flux, substitute it and I'm done. They don't know that there are things that are changing. We can have a circular loop, we can have a square loop, we can have a triangular loop but where does all of that link with the flux? So that's why I say I have to think for the learners because they like to say: 'Will it always be like this?' And I hate that questions. That's why I say we need start teaching them that, yes we have the formula for calculating the induced emf but inside the formula for induced emf we have the flux, inside the flux, we have the area and the field. Those things can change. And we also have the angle. They don't see that. They only see B times A cosTHETA. To them it's only THETA that's going to change. Sometimes it's zero, sometimes it's ninety. That's all they want to know.
Jared	**You wrote here as your answer to: What do you intend learners to learn about each key idea for C, calculations of emf, understanding of how to calculate the emf with the change in flux, field, area and time. How will you achieve this understanding**
Teacher	The time should be removed. Let's maybe put the angle there. I normally teach these things in parts. We usually start a simple thing of calculating the flux. With a straight forward only change in the angle. Like maybe calculate the flux of this square loop when the angle of the field to the normal of the surface area is maybe fifty degrees. So then the learner first understand just how to do field times area times cosTHETA. Then later on we'll change maybe magnetic field. After that maybe we'll change the area and then after that we'll change the angle. Sometimes you don't have to change the angle, you just have to change the wording that it started and ended…where if it's a circular loop, it started there and ended there. So they know we started at zero and ended at a flux of maybe twenty or twenty two. They need to know that we get the change there. I will start first with teaching them simple formula, just substitution then we'll go the field then the area that is changing. Also the area of centimetres to metres squared, from millimetres squared to metres squared, Because we teach them the conversions but Jared, you know not many of them remember that.
Jared	**Question 3 is: Why is it important for learners to know this key idea. So for key idea A, is electricity generation something that they study at any point?**
Teacher	Electricity generation in CAPS is not that too deep. We just do the highlights. Like in grade 9 we just teach them that we have different types of power stations. In grade 10 we only focus on the circuits. And in grade 11 that's where we just do that. Grade 12 we're only interested in the internal resistance. So we have to link it with the outside world. That's the only way our learners need to understand…or maybe they understand that, oh, there's a link between what we do in class with what we do outside. I normally tell them that some of you will work as electrical engineers, you'll be doing this in your line. But not all of them listen. I try at least to link the outside world.
Jared	**Just broadly, why is Faraday's law taught to learners?**

Teacher	Faraday's law goes with electromagnetic induction. A learner need to know that an emf is induced, the resistance can be able to determine the current that is flowing in the circuit. Or the maximum current that we can get. So I think it is important not for a learner to know we are producing electricity but how much of it can we produce.
Jared	**Are learners expected to calculate the current?**
Teacher	Examiners differ. I think with the questions that I've seen, I can say yes, the learners are required to calculate the current. But they are not required to calculate the resistance. They are mostly required to calculate the current and the emf.
Jared	**And how do they calculate the current?**
Teacher	They will use the emf, the equation ε = I.R. They resistance will mostly be given. The current is the one that we will be required. ε will be coming from Faraday's equation which is –N, change in flux over change in time.
Jared	**Then going by each key concept, what concepts need to be taught before teaching: Understanding electromagnetic induction?**
Teacher	I think that we should go back to magnets because a learner needs to know that there is a magnetic field. Because we link the field…we talk a lot about the field but the learner has to understand where the field comes from. The field has to be important. And then the learners understanding of electric current also has to be reviewed before we start electromagnetic induction because we link the current and the field. And going back to also the strength of magnets, the poles of magnets because as you know we can change the relative motion of the coil and the magnet by changing the poles. The galvanometer can face the opposite direction or can face the other direction. If we make it south the galvanometer will go the other way. The learner has to know the field lines between south and north, where are the lines going. They need to link that. So I will start first by doing the magnets then going back to just simple theory of electricity.
Jared	**What concepts need to be taught before the concept of magnetic flux?**
Teacher	The field, the surface area. The learner needs to know what they field is, what's the surface area is and when we talk about the flux and the angle changing, what we are talking about. The angle there, the learner should understand that it is the angle between the field and the normal line of the surface area. Not just any angle. So that one is important because they make a mess.
Jared	**What concepts need to taught before showing them calculation on emf?**
Teacher	Before I teach the emf equation we do a lot of calculations on the flux. The flux, the change in flux, I need to make sure that learners understand what the change in flux is before I start teaching Faraday's equation. And once I start teaching the change in flux it will be easy to apply the change in flux in the emf.
Jared	**The question of, consider the idea of teaching electromagnetic induction, what do you know about this idea and its connection to Faraday's law that learners do not know yet? So you think in terms of planning your lesson and teaching electromagnetic induction.**

Teacher	The right hand rule for me is always a mess. The difference between a current carrying conductor and a solenoid is also a confusion to learners. Also that we can use an electromagnetic field and be able to induce the current. That is something that is amazing to learners. So before you can start do that, you have to go back to the background of what they know so you can start teaching them that.
Jared	**Still based on the same question, if you consider the magnetic flux, what do you know about this idea and its connection to Faraday's law that learners do not know yet?**
Teacher	I don't know much about the flux except that we can link it with the field and the normal line. Mostly I would say the field is the one I knew a lot about but the flux I didn't have much theory on that. I only knew the ones that I wrote there. The first law of Faraday's law and the second one but I didn't read into them because we didn't look into them in CAPS. And also when we were in school we didn't do Faraday's law. I started seeing it in varsity but only just that one lesson. And we didn't focus more on it and we didn't do it in exams.
Jared	**You have mentioned some difficulties already that learners have. So they struggle with the right hand rule. How do you address this difficulty?**
Teacher	That one you have to be practical. You have to be creative. I start first with the simple thing, the current carrying conductor. They will have the pen in their hand. I will start teaching them how the current is moving, where the field is facing. Once they know those directions, I will start teaching them the right hand rule to get all three in one. But we have to start with that simple one, they know that if I have the pen in my hand, the coil will be represented by my fingers, the thumb is always pointing northwards. Then after that we extend the hand. That, OK this was the current, this was the field now this will be the other thing. I think after I have taught it that way things become easier. But we have to also do a lot of exercises, about ten or so to be able to understand. But even when we do revision, there will still be learners that are using the left hand. They will forget that we taught them the right hand rule. And there will be learners that don't know that this one is field, this one is current, they will still be asking those questions.
Jared	**You say for electromagnetic induction, learners always confuse magnetic field and flux. How do you address this?**
Teacher	Before I start teaching the flux, I will go first from the theory that they learn in grade 10 staring with the magnetic field, try to emphasise what the field is. We spend a lot of time on the field. When we get to the flux I need to explain to them because they start with the same wording 'Magnetic field' and 'Magentic flux'. So learners tend to misunderstand the two, mix the two. So I will explain that this one where we started from, this is the field. If I use a page, I will say the field is moving perpendicular but that is not the flux, the flux will be the one that we calculate using the surface area and the field passing through the surface area so that they understand I don't have the flux here, I will only have it if I calculate it but I can have the field passing through the area.

	And also before teaching that you have to go back to that coil, break that coil in half and say ‘I have a current carrying conductor and there are loops wrapped around it’ and you make a 2D sketch looking at the cylinder from the top view, what do you see? And I will tell them it’s a square or it a circular loop. As you are having coils around the current carrying conductor there is something there, there is a magnetic field around it. Then they start to understand this is the field then I can use the field to calculate the flux.
Jared	**You mention that learners struggle with the angle associated with the formula: Flux equals BACosTHETA. How do you address learners’ difficulty with finding the angle?**
Teacher	That one, I don’t know if it’s the understanding of the English but you will start explaining to them that if I have a surface area, there a normal line and If I have the magnetic field passing through that area, the angle we are talking about is the angle between the normal line and the field. The learners always confuse. They look at the word perpendicular, parallel, they start being confused. Even if they never mentioned any angle they will be thinking it’s perpendicular and so there’s no flux because the angle is 90 degrees. Then you have to explain to them that when they say the field is moving perpendicular they are talking about this is the surface area, the field is moving perpendicular to the surface area. So you need to be practical and learners need to use their pens to pierce through the paper so that they see what you have because if it’s me doing it, they look at me but now they need to get a blank page and use their pen, pierce a hole so that they can see that that is the field and then maybe use a ruler and say the ruler is the normal, what is the angle between the two? What If we change the field and you put it at another angle? What is the angle between the normal and the field? So that they can see practically how these two things are linked. Once they start reading and the field is perpendicular, they will tell you that the angle is zero and therefore you don’t have the flux.
Jared	**What are typical learner misconceptions when teaching electromagnetic induction?**
Teacher	A lot. Like I said, field and flux. When we calculate emf we have to calculate the current. They will tell you that it is impossible. They don’t know that the emf is involved, we can use the voltage to get the current. They don’t know that. Like I said also the angle is also a problem. The number of loops. Sometimes when the question comes and there’s no number of loops, the learner will substitute the number as zero because it is not given. The conversion of units. If they are given in centimetres squared already, it is a problem for the learners. They just divide by a hundred. They forget that that 100 was squared, Those are the problems that I have seen so far.
Jared	**Question 6 of what is your knowledge of learners’ thinking that influences your teaching of these ideas, you wrote for you key idea of electromagnetic induction**

	that they don't like the theory they just want to calculate. Why do learners just want to do calculations?
Teacher	You will remember that workshop that we attended where they said that we only absorb information in 8 seconds. The learners don't like the theory because they think it is a lot and it's a lot to remember. It's better to do calculations, you just read the questions, you substitute, there's only one formula. They only like that. They get the necessary things are needed to substitute into the formula and then the hard work is done. They don't want the theory. Any topic that we teach in physics and it has theory before we get to the calculations is a problem. But if it doesn't have calculations it's also a problem. I think we should remove one section in grade 11 and spend more time on electromagnetic induction.
Jared	**For the question: Are there any other factors that influence the teaching of electromagnetic induction?, you say there should be resources to help learners view the difference between flux and field. What resources did you provide or would you provide?**
Teacher	Do we have the ones where you can move the magnet relative to the coil?
Jared	**As in just a bar magnet and a solenoid?**
Teacher	Yes.
Jared	**Yes.**
Teacher	I didn't know. Because for that part I relied on the Youtube clip.
Jared	**What did the Youtube clip show?**
Teacher	It was just relative motion between the magnet and the solenoid. That there must be relative motion, if there's no relative motion, there's no reading on the galvanometer.
Jared	**What representations would you use in your teaching strategy? You've already mentioned the Youtube video.**
Teacher	And also the paper to show the angle. That is mostly what I have been using.
Jared	**How would you ascertain whether your learners understand or are confused about a particular idea? So regarding electromagnetic induction.**
Teacher	After teaching, here is exercises but I don't like exercises. Once in a while I will do what I call a throwback Thursday. You will find that we are maybe busy with a different topic but I wil come back and say, guys we are going to have questions on electromagnetic induction. For that 20 minutes. First of all what is electromagnetic induction. We start there just to gauge their understanding to see if they only relied on the notes or what they read. I will say explain it to me in your own words. Who remembers Faraday's law? Who can tell us the equation? Write it on the board. What is B? Call it by its name. What is its unit? What is A? That angle is for what? And no one will have a book open, we will just be talking about it. But if I see there were not too many questions answered, I will have those extra lessons, I will go back to that topic.
Jared	**If you were to set up a test on Faraday's law, what would you test for?**

Teacher	For Faraday’s law a learner has to explain to me if they understand what electromagnetic induction is. And before we can get to Faraday’s law, I will ask about the field and the flux. And just throw in the formula and ask one or two of what is in the formula and their units. Lastly for a 5 mark question I will ask a calculation. I won’t ask emf. I will give them the emf, I will give them the time. Or they will need to calculate the flux or the field having had the emf or the time. Or sometimes I will ask for the time just to change things around.
Jared	**Did you have class tests?**
Teacher	Yes, I had one. One was just the throwback Thursday.
END	

SARAH - PRE-INTERVIEW (SCHOOL 2)	
Jared	***I just want to confirm, you have identified two key ideas with the teaching of Faraday's Law.***
Teacher	Yes.
Jared	***So magnetic field and magnetic flux.***
Teacher	Yes.
Jared	***What will be the order that you introduce them?***
Teacher	First magnetic fields and then magnetic flux because magnetic flux is all about the field lines going through the coil where the current will be induced.
Jared	***What have you done so far with electromagnetism?***
Teacher	Ok electromagnetism, I will recap on the magnetic flux and the change in the magnetic flux and all of that. But I've gone through all of them. But not the actual induction of emf through the coil.
Jared	***Have you touched on flux?***
Teacher	I've touched on flux, yes.
Jared	***And how to calculate it?***
Teacher	Yes. I can recap if you…
Jared	***Ok, no that's fine. I just want to confirm what you've done so far.***
Teacher	I've done magnetic flux on Thursday.
Jared	***And magnetic fields, so that you've done as well as magnetic fields?***
Teacher	Yes.
Jared	***So today is purely introducing Faraday's Law?***
Teacher	Yes.
Jared	***When you introduced flux, did you have diagrams that you showed them, or notes?***
Teacher	We have this little built thingy, I'll show you in class. It's a coil, and then there's like two wooden blocks that represent the magnetic field or the two magnetics. So with the changing magnetic flux, I use that to explain the whole… I didn't use drawings. I cannot draw.
Jared	***On the topic of magnetic flux. Does it connect to any other topic that learners will learn about?***
Teacher	Other than Faraday's Law?
Jared	***Yes.***
Teacher	No. I don't think so.
Jared	***And Faraday's Law. Is there anything else that you think that it may connect to in the curriculum?***
Teacher	Um, the Grade 12 motors and generators, it'll link to that as well. But for Grade 11, no.
Jared	***You don't teach grade 12?***

	whole compass thingy. Or even turning the coil through a magnetic field to see how it changes. Simulations like that I find help sometimes.
Jared	***How are you going ascertain learners' understanding or confusion regarding these ideas?***
Teacher	Yoh, that one. Is it correct if I say, to help them to do better, you need to give them a lot of exercise. With more exercise they will get better with it. And to use different examples. Because I think they get more confident if they see how it's going to be asked in the test because sometimes it's a very loose topic, so more examples as to what we are going to do with this knowledge.
END	

LINDA - PRE-INTERVIEW (SCHOOL 2)	
Jared	***I just want to find out, your key ideas, is there a specific order in which you will introduce them or is it the same as you…***
Teacher	The order is the same as I have given there.
Jared	***As you've listed here?***
Teacher	Yes.
Jared	***For your key idea C, the magnetic flux and magnetic flux density, what sort of problems or difficulties do you think learners may have with these?***
Teacher	If you look at the units for example, it's difficult for them to comprehend the difference between magnetic flux and magnetic flux density. So the moment you start talking about tesla and weber, the concepts are so interchangeable that It's confusing so I'm going to try and clarify that for them.
Jared	***How will you? Will you use diagrams or…***
Teacher	Yes I've got diagrams.
Jared	***What difficulties do you think learners may have with Lenz's Law?***
Teacher	Lenz's Law is not technically required at this stage and it's not necessary for them to understand the concept as we are going to apply it later on to find the direction of the current. They do Faraday's Law of electromagnetic induction now and you hardly even need to use a solenoid and a magnet because next year they are just studying motors and generators. So they just have to understand the change in the flux. So traditionally we use the solenoid and we use the magnet that you push in or out and they have to learn that Lenz's Law is opposing the magnetic induction. But that makes very little sense to them because you teach it that way and then when you get a question, it's a loop or a coil that is turning in a magnetic field. So there's no relation to the way that you traditionally teach the concept and the way that it's eventually ask or applied in the motor or the generator.
Jared	***Do you introduce it to them at all?***
Teacher	I don't think I'm going to. It's not something I'm going to teach them today.
Jared	***The first part, the magnetic effect on a current, how will you introduce that?***

Teacher	The first one, the magnetic effect of current, I'm going to show them a video so that they just realise that if you have a current carrying conductor in a magnetic field, it will experience a force, so that they will understand there's a relationship between electricity or moving currents and magnetic fields.
Jared	***I'm going to take each key idea individually. For the first one: The magnetic effect of current, what concepts do learners need to be taught before teaching this idea?***
Teacher	My problem is the whole lesson isn't about the magnetic effect, the lesson is actually about the induction. But my problem was that learners do not comprehend the relationship between magnetism and current. So I think we should start with doing the effects of current first. I feel like in Gr 10 that is something that is neglected. And that includes everything, not just the magnetic effect. The heating effect, all the effects that current has and the magnetic effect. Because the magnetic effect is a magnetic field caused by the flow of current. Now what we did with Faraday was not actually the current creating a magnetic effect but the conductor reacting to a magnetic field. So the two concepts are intertwined but the children do not see the difference between the two clearly. So I think you should start with the effect of current which causes a magnetic field and then they have to realise that therefore it's the inverse that the magnetic field will also have an effect on flowing current. So they don't understand why a force is exerted because they don't even understand that the conductor itself has a magnetic field and it's the two magnetic fields actually reacting to each other causing the forces. So that's why I've started with the magnetic effect because they don't realise that that a current-carrying conductor has its own magnetic field and the force is the two magnetic fields reacting to each other.
Jared	***And then based on that, talking in terms of current or magnetic field, is there anything learners should know, even from previous grades, they need to understand?***
Teacher	Yes, I think we must place more emphasis on the shape of the magnetic field through different conductors. They have to understand what the magnetic field looks like around a straight conductor, around a loop, around a solenoid

	and those are all things neglected in the current syllabus. We don't have enough time to go into detail of each one of those. But I think it needs to be a progressive build up from start simple. And I mean the textbook mentions it, they have the pictures in it but you never do the experiment or you never spend enough time on that alone. So the concepts are progressing too quickly form that to the very complicated and missing the steps in between.
Jared	***Would you say CAPS doesn't give enough time to the concept?***
Teacher	Yes it definitely doesn't give enough time because I would rather progress more slowly and start with the more simple magnetic field or a simple conductor to a more advanced or complex conductor and magnetic field because eventually you want to get to…the previous syllabus did the straight conductor and then you did the simple loop and then you did the solenoid that has the same shape as the bar magnet but there was a slow progression. But now I don't have no time to go through all of that. So I jump from not simple but from nowhere to the solenoid and they do not understand where the shape of the solenoid is coming from because they don't realise that the solenoid is loops and a plain simple single loop came from a straight wire that was bent so I just want more time to spend on the steps in between.
Jared	***And then teaching and introducing magnetic flux. Is there anything that you would expect learners to know before that?***
Teacher	We have to pay more attention to the magnetic field itself. Again in a quantitative way and not only in a qualitative way. In grade 10 they do the shape around a bar magnet and that's about that with similar poles or opposite poles or a single bar magnet. And all of a sudden you introduce the concept of magnetic flux. But I think they should start calculating magnetic field strength earlier. They jump again from the shape and what it looks like to something very complex, the magnetic flux through the loop but they don't have a clue what magnetic flux is. So maybe you can start doing calculations about magnetic flux earlier when you introduce the concept of the magnetic field lines.
Jared	***The effect of magnetic field on current. Is there anything that learners should know before they are taught about this key idea?***

Teacher	You have to introduce Fleming's left hand rule and right hand rule for them to understand that properly. What I mean about effect of magnetic field on current is the fact that the magnetic field is going to exert a force on the current. But they never learn where the force is coming from because the syllabus gives no attention to Fleming's Left Hand Rule and Right Hand Rule. It's not even required in Grade 12 but it's still the best way to explain the dynamo effect or the motor effect. Nowhere do they officially teach that. The grade 11 CAPS document requires that you teach them just the Right Hand Rule and there are so many versions of the rule and how it's applied that that doesn't apply to what happens in a motor or a dynamo. So I would like to see the introduction of Fleming's Left Hand and Right Hand Rule because then they will understand where the force is coming from that is exerted on the conductor or on the conductor then. And that is also something then neglected. I always teach learners the effect of a current-carrying conductor but they don't realise even if you just have moving current like moving protons, that beam of protons will experience a force and be deflected. But you never have the opportunity to teach them that. They only see it in the context of a conductor.
Jared	***And for induced EMF, is there anything that learners should know before they are taught about this key idea?***
Teacher	No, I think if the previous three ideas are taught well then they don't struggle with the idea of the induced emf.
Jared	***If you think in terms of you're about to teach magnetic flux or you are busy teaching it, what do think you know about it that learners don't yet know? So you're keeping in mind that this is where we need to get to.***
Teacher	To me it feels like they don't know a thing. It's a very complicated subject which they don't even know the basics. So you try to get them to that complicated level without having any background on it. So it feels like everything I'm telling them is new to them.
Jared	***Would you say that anything here is totally new to learners?***
Teacher	The magnetic flux is a new concept to them and induction is a new concept. They don't understand induction either.

Jared	***Is there anything about emf that you know but that learners do not know yet?***
Teacher	The thing that they will never know, transformers operate on the principle of induction. But they haven't got a clue about what transformers are as nowhere in the curriculum are transformers covered. And yet they expect learners to understand when we do generation of electricity in grade 12, they talk about the electrical grid and using the step-down and step-up transformers. Not a single one of them can tell me what a transformer is.
Jared	***What are typical learner misconceptions when teaching these key idea?***
Teacher	There's not something I can think of specifically. This chapter to me is like you explain it and learners never understand anything about it. And then they get to grade 12 where some of this is applied but this is never assessed again, the detail around Faraday's law. There's many things around it that they can't apply. If you change the magnetic field or you change the angle of the loop in the magnetic field or you change the time or you change the rate of rotation, they can't cope with different factors being changed. To them it's too complicated, you need a lot of time to explain one aspect or factor in the equation. You can teach them one in class and then if you give them another one, they can't cope. The questions that are available in the textbook and the questions that come up in the papers are very one sided. They only change the magnetic flux. They never change the angle of the coil in the field or the number of the turns or never change the rate at which the change is taking place. So learners just get one side of it and if you change any other factor, they've got no idea how to cope with it. So in grade 12 they are just too relieved that this isn't being assessed again.
Jared	***You said for magnetic flux: "I use various diagrams to build up the idea of magnetic flux and the change in flux." Can you describe what diagrams you would use and what would you want learners to see from them.***
Teacher	Well it is diagrams where the loop or the coil or the twisted wire is illustrated and where the magnetic field is illustrated graphically. I will show them diagrams from the side, always a cross-section, because I hope that they

	will understand the concept of this invisible magnetic field that they can't see. I tried to present it visually for them so that they can have a concept of the magnetic field through the conductor.	164 165 166
	END	

Appendix V: Participants' transcribed post-interviews

Michelle: Post-interview (School 1)

MICHELLE - POST-INTERVIEW (SCHOOL 1)	
Jared	**How many years have you been teaching in total?**
Teacher	Second year. First year Science.
Jared	**Have you read this page, or these two pages from the CAPS document on Faraday's Law before?**
Teacher	Yes, in university.
Jared	**In university last?**
Teacher	Yes.
Jared	**Roughly two years ago?**
Teacher	Three.
Jared	**Did you go through these two pages before planning and preparing for your lesson on Faraday's Law?**
Teacher	No I used the textbook and an extra textbook also based on CAPS.
Jared	**What topic is taught before Faraday's Law or Electromagnetism in the Gr 11 syllabus?**
Teacher	It's Electrostatics. Electric field, all of that.
Jared	**Can you remember what topic is taught after Faraday's Law or Electromagnetism in the Grad 11 syllabus?**
Teacher	Isn't it electricity? Circuits I think.
Jared	**Are there any topics in the Grade 10 or 12 syllabus that influence this topic and the way you teach it?**
Teacher	Definitely electricity and electrostatics. So how they understand EMF and how electrons move through the circuit and all of that.
Jared	**What do you understand by "State Faraday's Law", which is the first point in the CAPS document? What do you think is expected of you?**
Teacher	Stress that Faraday's Law is related to the rate of change of magnetic flux, which is the product of magnetic field.
Jared	**Do you think there are any other ways to state Faraday's Law other than in words?**
Teacher	Yes, using the formula that is given in the textbook as well.
Jared	**CAPS says use words and pictures to describe what happens when a bar magnet is pushed into and pulled out of a solenoid connected to a galvanometer. How would you describe what happens when a bar magnet is pushed into and pulled out of a solenoid connected to a galvanometer in words for learners?**
Teacher	Ok so in words and pictures, I will, like in the notes, draw them a picture of a solenoid and a bar magnet and the different scenarios, how it can move from into the solenoid, out of the solenoid and then just explain it in words using the picture.
Jared	**What is this section trying to show learners with regards to pushing or pulling a bar magnet through a solenoid?**

Teacher	The EMF and the direction of the current. So is the magnetic flux going to form and then what direction is the current going to move and where is the north pole going to form and where is the south pole going to form.
Jared	**Did you explain this to learners in words?**
Teacher	Yes, but using an example in class first of a solenoid. I used a bottle and then showed with a pen, the magnet is moving into the bottle and out of the bottle. And then in which way is the current going to move using my fingers. And then after that I draw them a picture on the board they copied and I explained it like that as well.
Jared	**The CAPS document says to first state Faraday's Law, then show the right hand rule, then introduce magnetic flux, ensure that learners know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux and lastly, calculate the induced EMF and induced current for situations involving changing magnetic fields. That is basically the order given in the CAPS document. Would you introduce these concepts in the same order? So you can have a look at them first.**
Teacher	Think I will introduce the magnetic flux before the right hand rule and all the calculations. And then do the right hand rule and the induced current flow which is after each other.
Jared	**Why would you introduce it in that order?**
Teacher	First because in the textbook as well they didn't really say a lot about magnetic flux and the whole concept goes around magnetic flux. So first maybe just introduce them to magnetic flux and maybe link Faraday's Law to magnetic flux so they understand it better and then do the right hand rule. Because if they understand the right-hand rule they will obviously know how the current will flow and how the magnetic flux is going to change then.
Jared	**Did your learners have any difficulties with flux or its formula?**
Teacher	They struggled with the flux. In the test we asked them to indicate direction of the current and they struggled with that. But they were fine with stating Faraday's Law and using the formula.
Jared	**How did you address the problem they had with finding the direction.**
Teacher	We still have to do revision on the test.
Jared	**Ok, so you haven't addressed it yet?**
Teacher	No.
Jared	**When showing the formula of Faraday's Law, you asked learners what the negative in the formula means. A learner replied that the magnetic field lines oppose each other. Had you spoken about the formula before this and the negative in it?**
Teacher	No, just telling them so the negative is to oppose so it's going to be in the opposite direction. And then also use the bottle to explain how it opposes. But that was the first.
Jared	**Just explain, if you don't mind, what is opposing what?**

Teacher	So if they say they push in the solenoid, it's going to make the magnetic field more so it's going to then be, say it's a north pole, it's going to form a north pole closest to the north pole to push it away. Because the magnetic flux stays constant, to keep it constant.
Jared	**Just to clarify, had you dealt with that concept of the induced field opposing the magnetic field before you introduced Faraday's Law?**
Teacher	I can't even remember.
Jared	**No problem. Did you pick up that learners had any other difficulties with any other concepts taught regarding Faraday's Law?**
Teacher	Not yet. I handed them extra activities of previous exam papers and they were fine with it. It was just to get used to the different scenarios and how it works. And to learn the formula and Faraday's Law as well.
	Post-interview paused for the day.
Jared	**Post interview, Part 2. The CAPS document says calculate the induced EMF and the induced current for situations involving a changing magnetic field. What other factors other than a changing magnetic field could induce an EMF in a solenoid.**
Teacher	It's that list right?
Jared	**In the textbook?**
Teacher	Yes.
Jared	**No, I'm not sure. I haven't looked at the textbook.**
Teacher	I can't even remember.
Jared	**If I can change the question. Are there other ways, other than changing the magnetic field to induce an EMF?**
Teacher	There is surely, otherwise you wouldn't have asked the question. I can't remember. Let me just read.
Jared	**Would you like the textbook?**
Teacher	Yes, do you have it? Can I read the question? It's that area, the strength, the rate and the number.
Jared	**Alright. Is that something you've seen now in the textbook?**
Teacher	Yes, this formula. So all of this is going to have an influence on EMF.
Jared	**Alright, so the variables as you see them in Faraday's Law?**
Teacher	Yes. The windings, the change in magnetic flux. So that will be the magnetic field and the area and the angle and then the time elapsed.
Jared	**What other factors other than changing the strength of the magnetic field could bring about a change in flux?**
Teacher	The area and the angles. Is its parallel to the surface or perpendicular or at an angle.
Jared	**OK. Do all of these factors, or rather, did you show these different factors that could affect the change in flux to the learners?**

Teacher	Yes. So we did the Faraday's Law in the formula. And then each one, there were different questions asking them what would happen to the induced EMF if you change the area, say from a circular coil to a square coil or the other way round. And then the relationship between, say the magnetic field and the induced EMF we did. And the change in magnetic flux and the area as well.
Jared	**Those questions that you're talking about, are they in the textbook?**
Teacher	No, it's previous exams. 2016, 2017.
Jared	**Was it also something you discussed after having taught Faraday's Law?**
Teacher	Yes. After I taught it I went through the question papers and did that with them.
Jared	**So it wasn't something that you taught separately, changing of the area? You just dealt with it as it came up with the questions?**
Teacher	Yes.
Jared	**Did you show any practical examples of how each of these factors affect the magnitude of the induced EMF or the change in flux?**
Teacher	No.
Jared	**Was there a reason for not?**
Teacher	Time.
Jared	**CAPS says to show a practical demonstration. They also list resource materials: resource materials: a solenoid, bar magnet, galvanometer and connecting wires. You say you did not show any demonstrations.**
Teacher	Just with a bottle and a pen.
Jared	**What were you trying to show with that?**
Teacher	So the bottle was the solenoid. Then the pen was the bar magnet, so pushing it in and what will happen to the magnetic flux and pulling it out, what will happen to the flux. Explaining this is when it is moving in the magnetic flux will increase inside the bottle but we want to keep the magnetic flux constant so what induced north or south will form closest to the bottle, magnet.
Jared	**What does that relate to? Why did you teach them that specifically?**
Teacher	Just for the right-hand rule in a solenoid. So the first one was the right hand rule. There were three different scenarios where you have to do the right hand rule and that was the last one. To see if your thumb points in the induced north pole, in what direction will your fingers move and that is the direction of the current.
Jared	**You spoke of doing an experiment with the learners on how to make an electromagnet as an intro to the topic of electromagnetism in your CoRe document. Did you show this to learners?**
Teacher	I showed them a video on Youtube where they made an electromagnet. And then they had the practical as well to do last term, after Faraday's Law.
Jared	**After Faraday's Law?**
Teacher	Where they had to make an electromagnet as well.

Jared	**What specifically did you want you learners to see from the video in which the electromagnet was being built?**
Teacher	So just how you can change…if there is a current flowing through, say it's going to attract any Ferromagnetic material, otherwise not.
Jared	**Ok. How does that lead up to Faraday's Law? How does that connect to the idea of Faraday's Law?**
Teacher	Ok to show them the induced current and the induced EMF. And then some of them made the windings so it was a practical example of what was going to influence the EMF. So the amount of windings. Some of them used screws with copper wire around. Then it showed them that the amount will influence the induced EMF. And if it's connected, the current will flow through. If not, it won't attract any ferromagnetic material.
Jared	**You chose to do question 3 in DocScientia as your first example of Faraday's Law with the learners.**
Teacher	Question?
Jared	**Three, from exercise 80. Was there any particular reason for choosing question 3?**
Teacher	No I did an example. I first did the two examples.
Jared	**From DocScientia?**
Teacher	Yes. There was an easier one. I think it was this one. Because I didn't want to start with one of these.
Jared	**An example on page?**
Teacher	251, I think so If I remember correctly. Because I didn't want to start with 3 because I didn't do the perpendicular, parallel and at an angle yet. I first explained Faraday's Law and then I did an example and then the lesson after that we did the angle. These on page 252 where it's parallel to the surface, perpendicular or at an angle to the surface. And this one says it moves perpendicularly through.
Jared	**Ok what does the first example you did deal with? Did it say at a specific angle?**
Teacher	Yes, it says…it was an obvious, easy one. They gave you the area and you had to calculate the induced EMF. And they gave you magnetic flux and they gave you turns. You just had to substitute into Faraday's Law and find the difference between the magnetic flux.
Jared	**So just say again, was the change in magnetic flux given?**
Teacher	No, you had to calculate the EMF first and then you had to…they gave you the rate at which the magnetic flux changes and then you had to calculate the change in magnetic flux. They also gave you the area in question B. I can't even remember this stuff.
Jared	**After doing a question from the textbook, you told the learners that there are more difficult questions. What are these questions that you refer to as more difficult and why do you consider them as being more difficult?**

Teacher	Ok, it's definitely the one where there is an angle. So the angle is a straight forward one where they just give you an angle, but when they use perpendicular or parallel, you have to know which one is equal to cos0 and which one is equal to cos90. And then all the exam papers I did with them, they give you an angle and then they say at the final position it was perpendicular to the surface, or the magnetic field was perpendicular to the surface. So they have to know then that it is cos0 and it adds up to one. Or if it's parallel is cos90 and it adds up to zero. So that is the more difficult…and where they give you not only one position but two and you have to find the difference inside the formula.
Jared	**So you're basically saying the easier questions are where they give you the angle value. And then the more difficult ones…**
Teacher	Yes the more straight forward question where you just substitute into Faraday's Law. And then the more difficult questions is where they want you to substitute the formula for change in magnetic flux. So the BAcosTHETA into Faraday's Law formula and then find the unknown.
Jared	**After doing this question, you discussed Lenz's Law. The CAPS document doesn't mention the words 'Lenz's Law'. Why did you choose to tell them about Lenz's Law?**
Teacher	It was in the…what was that book's name? That red and white book. That extra activity book we use with the question papers in?
Jared	**With past question papers in?**
Teacher	Yes. What's its name? I'll send you the name. But I work from that book and this book because this book is not always explaining it the best. So I use this book and that book. So they immediately gave the definition for Faraday's Law and after that they have the definition for Lenz's Law.
Jared	**So the definition for Lenz's Law was also given? Did you give them the definition for Lenz's Law?**
Teacher	Yes, the definition for Lenz's Law was on the notes I handed out to the learners.
Jared	**Why's it important for the learners to know how to determine the direction of the induced current? Why do we expect that of learners?**
Teacher	Can you tell me Lenz's Law again?
Jared	**So just as a reminder of Lenz's Law, it says that the induced EMF will set up a current that will oppose the original change in flux. Why is it important for learners to be able to determine the direction of the induced current?**
Teacher	So I think it's important because the practical example that I did was an example of showing them the magnetic flux doesn't want to change, it wants to stay constant. So for that you need to find the induced north pole, your thumb faces in the north pole. And then your fingers show the induced current's direction. Is it that? I can't remember this stuff, really.
Jared	**Are you aware of how to calculate the induced current in a loop?**

Teacher	Yes, you can use Ohm’s Law. It depends on what is given to you. There was one example we did but we did it with Ohm’s law.
Jared	**So you did show this to learners?**
Teacher	Yes it’s also in the textbook. It’s in page 254 as well.
Jared	**Why did you show learners how to calculate the current if it’s not directly expressed in the CAPS document?**
Teacher	I don’t know, because I didn’t use the CAPS document.
Jared	**You didn’t use the CAPS document?**
Teacher	I used the other book.
Jared	**Is it just because you saw it being asked in textbooks?**
Teacher	Yes, so usually we don’t know what they are going to ask us so I used…the other textbook focused on Faraday’s Law and then they did immediately Lenz’s Law afterwards and they asked combined questions at the back of the book. That’s why I did Lenz’s Law as well.
Jared	**Although the CAPS document doesn’t speak of Lenz’s Law, is it in any way implied in the CAPS document? Or does the CAPS document not mention Lenz’s Law at all? So I’ll give you a moment to look through it.**
Teacher	They say in the CAPS document, the fifth point from the top, know the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux.
Jared	**So is that basically dealing with…**
Teacher	Yes that’s dealing with Lenz’s Law.
Jared	**Where in real life may learners come across the induction of an EMF in a conductor as explained by Faraday’s Law.**
Teacher	Oh yes, isn’t it that in copper wires and…is it this? The overhead cables…no. It’s not that, that’s electromagnets. I know this, I wrote down so many examples for them. It isn’t in the book.
Jared	**Did you give learners examples?**
Teacher	Yes on the notes I gave them examples of electromagnets and induced EMF in our daily lives. I really can’t remember this.
Jared	**Ok that’s fine. Can you just email me those notes?**
Teacher	Yes, that I can do.
Jared	**After having taught the topic of Faraday’s Law, is there anything that you would change about the way you taught it?**
Teacher	Think maybe make use of more practical examples so the learners can understand it better from the start.
Jared	**What kind of example would you like to show them?**

Teacher	So the same as the CAPS document, you use the solenoid and the bar magnet and the galvanometer and connecting wires and show them how it looks. And then maybe just make use of the solenoid and bar magnet instead of a bottle and pen.
Jared	**I would just like to come back to the topics taught before and after Electromagnetism and Faraday's Law. As you had mentioned, before is Electrostatics and circuits afterwards. Do these topics in any way affect the way in which you taught Faraday's Law? Anything about them that you keep in mind when teaching Faraday's Law?**
Teacher	I don't know. Just the EMF that has to do with circuits. And electrostatics, no. In electric circuits they also talk about the EMF and the influence and then you use the different formulas to calculate. So that's where we use EMF as well and electrostatics has nothing to do with…or I didn't fall back on that.
Jared	**I would just like to return to your CoRe document and just ask a few questions on this. So you can have a look at your answers if you want. For your Key Ideas A, *Change in Magnetic Field*, you mentioned in your first interview that you want to explain on the board where you measure the final and initial flux. What did you mean by that "where you measure the final and initial flux"?**
Teacher	I think It was where, it's where you move the magnet into…say if the magnet moves outside of the solenoid, you will measure the magnetic flux initial there and then the final position is inside, the magnetic flux will be inside the solenoid.
Jared	**You Key Idea B of an *Induced EMF*. What do you think your learners' understanding of EMF is? How do they understand EMF?**
Teacher	I think they struggle with EMF definitely because they can't really relate or see something happening Immediately so…
Jared	**How do you mean they can't see something happening immediately?**
Teacher	There's nothing moving that they can see now like there. So we talk about EMF in circuits and everywhere but they can't physically see or touch, like the magnet is moving then everything is happening so you can show them the magnetic field lines but they can't see EMF like there.
Jared	**What do you think that they understand EMF as being?**
Teacher	I don't know. What did I write?
Jared	**If a learner asked you what EMF is, how would you explain it?**
Teacher	Electromotive force.
Jared	**And if they asked you what does that mean?**
Teacher	Then I'll give them the definition that I can't remember now.
Jared	**Did a learner ask you at all what is EMF?**
Teacher	No.
Jared	**Have learners dealt with the concept of EMF before?**
Teacher	So I did Faraday's Law and no one asked me what was EMF is. They just asked about the magnetic field lines and the relationship between say the area and the EMF.

	Everyone wanted to know what is the area's influence or the magnetic field strength influence or the angle's, but no one asked what is EMF and what is going to happen to that, we just say it's directly proportional or indirectly proportional. That's the only thing I explained to them.
Jared	**Have learners come across the concept of EMF before?**
Teacher	I think they had touched it in grade 10. But not with Faraday's Law but with circuits.
Jared	**To go back to your answer of "an EMF may be generated by changing the magnetic environment." How can you change the magnetic environment if you could just elaborate?**
Teacher	You can change the strength of the magnetic field or if you change the magnet's position.
Jared	**Why do we teach Faraday's Law to learners?**
Teacher	I think for them to understand how the stuff works, but I can't remember. What they use Faraday's Laws in their daily lives with the stuff we have that's working with Faraday's Law for them to understand it.
Jared	**What concepts need to be taught before teaching the idea of a change in magnetic field? What do you feel you should have taught for teaching them about a change in magnetic field**
Teacher	Definitely the basic magnetic force, so say north to north, south to north, that around a bar magnet are magnetic field lines. Because there in Gr 10 they did a whole chapter on magnetic fields and how to draw them and what to do and how to calculate them. I think they need to do that before they can change in magnetic field.
Jared	**Did you revise any of that about magnetic fields?**
Teacher	No.
Jared	**What concepts need to be taught before teaching about magnetic flux?**
Teacher	So I think you have to do that one last. So in Faraday's Law, so just revise all the others and then that because it's a new topic for Grade 11 they didn't do any magnetic flux in gr 10. So just maybe before teaching that make sure that they have basic knowledge of magnetic field lines and then just start with the definition of magnetic flux and how magnetic flux can change and what is going to influence the magnetic flux.
Jared	**If I can just ask, you said do that last. Are you saying teach magnetic flux after Faraday's Law?**
Teacher	No first do the basics like what is a magnetic field, what is EMF, and then do magnetic flux because it's a new concept for them.
Jared	**Oh alright. Again, what concepts need to be taught before teaching the idea of *Induced EMF*?**
Teacher	I think just fall back on what is EMF and then explain what does induced mean and how is it going to be induced with the magnetic field and what is going to influence the induced EMF as well.

Jared	**And then on *Induced current* what concepts need to be taught before teaching *Induced current?***
Teacher	Definitely induced EMF and the magnetic flux. That is how you're going to find the direction of the induced current.
Jared	**Consider the idea of teaching *Change in Magnetic Field.* What do you know about this idea and its connection to Faraday's Law that learners don't know yet?**
Teacher	What?
Jared	**So if you consider the idea of teaching *Change in Magnetic Field, w*hat do you know about that, that learners don't know yet? Or on any one of your teaching ideas?**
Teacher	I really don't know.
Jared	**Can you identify or think of any typical learner misconceptions that learners may have on any of your Key Ideas?**
Teacher	Definitely. They can get confused with where the magnetic field is at an angle so they give you parallel, perpendicular, it's opposite. So perpendicular is zero degrees, cos0, and parallel is cos90. So I saw when I did the past papers with them, they struggled with that idea of getting used to why it's like that. I re-explained it again. Same as on page 252 and then they struggle with getting the direction of the induced current because they usually face their thumb in the north direction of the bar magnet and not in the induced north. So then they get the induced current wrong as well.
Jared	**You mention for: *What is your knowledge about learners thinking that influences your teaching of these ideas,* for *Changing Magnetic Field",* learners struggle to understand the concepts because it can't be seen with their bare eyes". Is this something to do with magnetic fields?**
Teacher	Yes.
Jared	**What is important for learners to know about magnetic fields that relates to Faraday's Law?**
Teacher	I think first you have to do the basics stuff of magnet fields that's in Grade 10: How does a magnetic field look and it doesn't cross and it's from north to south. And then you have to be able to know what the magnetic field strength has to do with magnetic fields. As well as at what angle it's going to have an influence on Faraday's Law, the angle of the magnetic field to surface.
Jared	**Of the solenoid?**
Teacher	Yes.
Jared	**So you've already explained what representations you would use in your teaching strategy. Is there anything you would like to add to that? Something you would specifically like to show them? A picture, a simulation, a demonstration?**

Teacher	Yes, next year I will make use of more practical examples to make it easy for them to understand. Maybe just to show them an example on, or a simulation where it happens and then start explaining so that it’s not that farfetched for them.
Jared	**Last few question. If you were to set up a test on Faraday’s Law, what would you test for?**
Teacher	Definitely the part where the relationship between say the induced EMF and the say the area or the magnetic field strength. And then definitely the change in magnetic flux; do they know the right hand rule. And then where the angle, say form the initial position of perpendicular to an angle of 45 degrees for example to just be able to see do they know where to substitute the angle and which one is equal to zero, which one is equal to 1 because that is confusing them.
Jared	**Did have any test on this with your learners?**
Teacher	I did an informal test and then they had one question in their SBA test on Faraday’s Law.
Jared	**Do you still have that informal test you gave them? Can you email it to me?**
Teacher	Yes, it’s on the notes.
END	

TEBOGO - POST-INTERVIEW (SCHOOL 1)	
Jared	***How many years have you been teaching?***
Tebogo	This is my eight year.
Jared	***How many years of those are teaching Physical Science?***
Tebogo	I only spent one year without teaching Physics. I taught Maths.
Jared	***How many years have you been teaching grade 11 Physical Science for?***
Tebogo	The same amount of years. So seven.
Jared	***What are your university qualifications?***
Tebogo	I have an MSc in Applied Radiation Science or Nuclear Science. And I have an Honours in Mathematical Science, BSc Chemical Engineering Sciences. And I have a PGCE in Education.
Jared	***What is your first language?***
Tebogo	Sepedi.
Jared	***Have you read the page on Faraday's law in the curriculum?***
Tebogo	I read it the first two years. Now and then I refer to, like where I should be.
Jared	***So you didn't go through it before planning your lesson?***
Tebogo	No.
Jared	***Other than the work schedule, what else did you use to prepare your lesson?***
Tebogo	I mostly look at the weekly planner because I like to be at least one week ahead in case something happens, and the ATP just to check where I should be.
Jared	***Did you use any resources for content?***
Tebogo	I would read through some of the summarised notes on the website, especially on those Mindset channels. I would steal some of their questions, especially some of the basic ones where we are introducing the topic. And I will read the textbook that the learners use so that I know which pages to refer them to when I'm giving them the exercises.
Jared	***What topic is taught before Faraday's law or electromagnetism in the Grade 11 syllabus?***
Tebogo	We teach first Electrostatics. Then we go to Electromagnetism which is Faraday's. Then we get to electricity in term 3.
Jared	***Are there any topics in the Physical Sciences curriculum that you would say influences your teaching of Faraday's law?***
Tebogo	Magnetism should be there.
Jared	***Are there any topics in Grade 12 that are related to Faraday's law?***
Tebogo	I think generators because we are inducing a current there. And with the generators we get to work with the coils and explaining how the generator works. And we have to do a recap of that when we do generators. And also electricity. Because Eskom produced electricity by using coal, heating the water with coal. The core part of what happens with electricity is in the generators and electromagnetism.

Jared	***The CAPS document says to state Faraday's law. What do you understand as CAPS's expectation with regards to your lesson?***
Tebogo	The learners should know the formula and how to define Faraday's law. And also know what each variable means and what the units are. So for me when they say "state", it doesn't only mean the definition.
Jared	***Would you say there is any other way to State Faraday's law?***
Tebogo	These day's they specify, they say "in words". Because the learners' use to get away with murder. They will just write the equation because the equation is also Faraday's law. Is there any other way, yes. Learners can use their own words.
Jared	**The CAPS document says to use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer. What is the expectation when you are teaching your lesson?**
Tebogo	When kids are little, we amuse them with a rattle. Too many colours and the sound. We get their attention with those things when they are young. And then when they are older, we only use one method, chalk and talk. If I explain and I have a magnet and I have a coil and maybe I have a galvanometer, learners will see that if I move, something is happening. Then I have to explain why there is movement of the needle on the galvanometer. When I move the magnet relative to the coil or the coil relative to the magnet so that the learners sees. And then after showing them that, I can then explain 'What you saw there is a current that is being induced, or the voltage that is being induced.' Then they will be able to link what I am saying to the diagram. But if I'm standing here saying 'Guys, it's like a magnet…', without a picture, some of them have never seen a magnet in their life, some of them will switch off. I believe in showing them. If you have something to demonstrate it, then call one of them and say 'You do it and let's see. Will there be movement on the galvanometer? Do it fast. Let's see if something will happen. Do it slow. Put it stationary there in the solenoid and see what happens.' Then they will see that there must be movement without. Without movement, you cannot induce anything. With pictures, I think it's more of to make them understand better and make them more attentive.
Jared	**Would you say there are any specific difficulties that learners may have with that specific representation?**
Tebogo	Mostly it when we get to use the Right Hand Rule where the coil and the fingers. You know that difficulty of the solenoid and the current-carrying conductor. The opposite there. The learner tend to use fingers for something else to represent the force and then they tend to use the thumb to indicate the current when it's not supposed to. I think it's only that confusion for the current-carrying conductor and the solenoid. Because with the current-carrying conductor, this is the current, and

	this is the magnet, but with the solenoid it's the opposite. When you get to the Right Hand Rule, learners tend to lose it. Especially the left handed ones.
Jared	***What representations did you use regarding induction of emf?***
Tebogo	I played a video. So where the magnet doesn't move, it shows the galvanometer is zero. The man in the video also increases the speed of the magnet so that learners see how that needle moves. Then he brings the magnet just closer to the coil and nothing happens. Move it in and keep it there, nothing happens. Move it in and out, they see there is relative movement between the magnet and the coil. And the more he increases the pace of the magnet or the coil, something happens.
Jared	***Is there anything that learners should know already before showing and explaining this demonstration to them? Their prior knowledge.***
Tebogo	I think Ohm's law is important. Because when I talk about the current that is being induced, the learners doesn't see any circuit there. So I have to explain there using Faraday's law because the emf is indeed the voltage. Let's say grade 10 electricity and magnets where they know the north and south of the magnets. Because sometimes if we swop the north and the south, learners have to know what is happening there with the Right Hand Rule. Also relativity. Whenever we say relative motion, it involves two objects. One of them has to be moving. Because learners tend to think that both of them need to be moving; one has to be still. And relativity is also in grade 10. It used to be in grade 10. They took it to grade 11. So I think relative motion is also one of them.
Jared	***CAPS says to first state Faraday's law, so it's in the order of these bullets, then show the Right Hand Rule, then introduce magnetic flux, ensure that learners know the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnet flux. And lastly, to calculate the induced emf and induced current for situations involving changing magnetic fields. Would you introduce these concepts in the same order?***
Tebogo	The calculations is the last part that I did. Because in between the questions of the calculations, that's where they talk about the solenoid and where they talk about the current-carrying conductor. So my major focus for two or three days is mostly on what is a current-carrying conductor. So I will give them activities to explain the direction using the Right Hand Rule. And once I see that we are getting somewhere, the current is moving into or out of the page, once they have that understanding, then I will introduce Faraday's equation because now we know all these things. Now I can actually calculate the induced emf. The way they put them there, first the Right Hand Rule, north, south, swop the north and south, what happens to the galvanometer when you swop the poles. So we will play around with a solenoid. I like seeing them doing those things using their hands. To me, it makes me see they are doing something. So after I see that they are understanding, I will start introducing magnetic flux. And with flux, I will focus on different areas; a

	square, a circle. Then at the end I will say, 'This is why we're doing all of this. We are putting them together'. Order, it's important. That is why I will teach them like that.
Jared	***What was your reason for first showing learners a video of electromagnetic induction before stating Faraday's law?***
Tebogo	Faraday's law only explains what we see. It is not induction itself. Learners must see what is happening and then you try explain it.
Jared	***You already mentioned Faraday's law before introducing magnetic flux in your lesson.***
Tebogo	Remember, I want them to know that 'Guys, this is the sub-topic that we are going to do. This is the formula. The formula has these variables. One of them is the flux'. But now I will only be focused on Faraday's law that day just to introduce the topic. Maybe one or two things. 'If the emf increases, what will happen to the time?' Those direct proportionalities. Then I will start to introduce 'What is this emf that they are talking about.' Then I will show them the Right Hand Rule. After that, I will say 'Guys, do you remember this formula? What do we call it? Faraday's law. Today we are only going to focus on these variables'. I will go back to the notes where it says one of the things to increase the emf is the number of coils. And tell them why it will increase or why it will decrease. And I will get to the areas. We are going to look at different loops. Some of them will be circular, some of them will be rectangular. 'How are we going to calculate the area?' After that I will then say let's calculate the flux, then the change in flux. The definition is the first then the simulation.
Jared	***What difficulties could learners' have regarding magnetic flux?***
Tebogo	That one is always a problem. First of all, flux and field. Just by saying 'With a magnetic flux of…' they think its field. The units also, they swop them abound. When we have to calculate the change, it's a problem.
Jared	***Were there any difficulties that you addressed in your lesson, or that you planned for or that arose during your lesson?***
Tebogo	A difficulty that I realised, you have to backtrack once in a while. And you get angry because you have to redo the work that you did that you thought learners understood. Learners switch off on a Friday. During the weekend they don't do nothing.
Jared	***Are there any misconceptions that learners may in their prior knowledge or in the topic of Faraday's law that will negatively affect their understanding of Faraday's law?***
Tebogo	Learners think that only if the magnet is moved will there be current but it doesn't matter which one moves. There must just be relative motion between the solenoid and he magnet.

Jared	***CAPS says to 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. Why do learners need to know how to determine the direction of the current?***
Tebogo	For the current. If we know the direction of the magnet, either north or south, it's going to be important to determine the force and the direction of the current. Or also if you know the direction of the current, you will be able to determine the direction of the magnet and the force. So without one, you can't get the two. So if you have the direction of the current, you will be able to say the magnet was either south or north. Also in grade 12, we are dealing with the same thing with the coil. If they don't then, it's a problem again in grade 12.
Jared	***CAPS says that know for a loop with an area A in the presence of a uniform magnetic field, the magnetic flux passing through the loop is defined as $\Phi = BA\cos\theta$, where θ is the angle between B and the normal of loop of area A. This statement is broad and seems to indicate that learners should only know the equation magnetic flux. Is showing the equation and explaining the variables as they are in the statement sufficient for learning?***
Tebogo	Like I said, the paper and pen. Piercing the paper with the pen. That is the best thing. That's the activity that we did to understand the angle between the normal and the field. Those will be going out, the normal line will also be going out. So you cannot explain it just like that. If the angle is not included and they 'parallel' or 'perpendicular', they think it's something else, that if you substitute cos90 there, it's a problem for a learner. You have to demonstrate what the normal line is. What the field is. So I use a pencil and a pen. The pen is the field. I will say the moment we tilt the pen, the angle between the normal line and field changes. But if I say they are parallel, the angle between them is zero.
Jared	***Caps says know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux. What do you consider as important when teaching this idea?***
Tebogo	With that simulation that I have, when you put in the south, the galvanometer will go in a different direction that when you put in the north. So show them that you can change the direction by changing the magnet.
Jared	***The CAPS document says to calculate the induced emf and induced current for situations involving a changing magnetic field. This statement is broad and indicates that learners should know the equation to calculate induced emf. Is showing this equation to learners and explaining the variables sufficient for learning about Faraday's law?***
Tebogo	If you don't break it down into little pieces and you go straight and say 'Today we are calculating emf. This is the problem. Let's see how we are going to solve it.' and you just calculate the flux. And the flux is a mixture of the field and the area. Ah!

	And there is the angle there, you are talking three different things in one. Many of them are not going to understand. But if you break it into little pieces, then at the end you can say that this is why we calculated the area, to get the flux. Then you vary the angles. Then you use the words such as ‘parallel’ and ‘perpendicular’. Then after you start bringing in a circular loop. Then you make sure it is changing, an initial and final. This is the kind of topic that you need three or four more days.
Jared	***Are you aware of Lenz’s law, and if so, what does it refer to?***
Tebogo	Yes Lenz’s law explains the direction in which the current will be induced.
Jared	***Does the curriculum refer to Lenz’s law at all?***
Tebogo	The curriculum doesn’t say that Lenz’s law must be stated to learners but the idea is spoken of in the curriculum. When we explain the Right Hand Rule and the direction of the current, we are referring to Lenz’s law which explains why the current is set up in a specific direction. So I don’t tell them the law but they are still taught the idea. You also need to explain the presence of the negative sign in the formula for Faraday’s law which is Lenz’s law. But at this stage we only tell them that the negative shows that the emf is set up in a way so that the induced magnetic field generated by the current opposed the change in flux through the solenoid.

SARAH - POST-INTERVIEW (SCHOOL 2)	
Jared	***Just two background questions, how many years have you been teaching?***
Teacher	This is my sixth year.
Jared	***How many years have you been teaching grade 11 Physical Science?***
Teacher	Five.
Jared	***Then the CAPS document. Have you read this page from the CAPS document on Faraday's Law before?***
Teacher	Not recently, no.
Jared	***So you didn't go through it before planning your lesson or preparing for your lesson on Faraday's Law?***
Teacher	No I did not.
Jared	***What resources or materials did you use to plan your lesson?***
Teacher	I used the textbook. I just look at what they have to know about the topic and then YouTube videos.
Jared	***What topic is taught before Faraday's Law or electromagnetism in the curriculum?***
Teacher	Before electromagnetism it's electrostatics.
Jared	***And the topic taught after?***
Teacher	After is electric circuits.
Jared	***Do they in any way relate to this topic?***
Teacher	Maybe the electric circuits a little bit because you're working with current and EMF again. But the electrostatics not really that I can think of.
Jared	***Are there any other topics in grade 10, 11 or 12 that influence this topic and the way you teach it?***
Teacher	Grade 10, it would be magnetism. But then grade 12 the motors and generators is based on this, Faraday's Law.
Jared	***What do you understand from the CAPS document in saying "State Faraday's Law"? What is expected of you?***
Teacher	"State Faraday's Law" is just that part of when the conductor…so it's basically the law itself that they have to understand and be able to state of when a conductor and a magnetic field moving relative to one another, an EMF is induced. And then the relationship between the EMF and, basically that it's directly proportional to the rate of change of magnetic flux.
Jared	***Are there any other ways to state Faraday's Law or represent it?***
Teacher	You can probably do it with the proportionalities. If I look at the CAPS document and exam guidelines, they don't really give anything other than those words.
Jared	***It says use words and pictures to describe what happens when a bar magnet is pushed into or out of a solenoid connected to a galvanometer.***

	How would you describe what happens when a bar magnet is pushed into or out of a solenoid connected to a galvanometer in words for learners?
Teacher	Ok, so in words, I will explained that it's the induced current that is created. So I will explain it with…I didn't only use words, I use a solenoid and a magnet. So I just tell them that if you push the magnet in, this pole then induces another magnetic field in the solenoid. So with the Right Hand Rule, you get the direction of the current that is induced. So I explain the whole inducing of a current with the magnet pushed in and pulled out.
Jared	***Alright so you showed that to learners?***
Teacher	Yes, I showed that to learners.
Jared	***Did you say that there were diagrams that you used?***
Teacher	I did not use diagrams, I used the actual solenoid and we practiced it with our right hand.
Jared	**Can you explain how you taught learners to apply the Right Hand Rule like you did in class so that I can have an idea of how you taught it?**
Teacher	OK so told them that since a current can induce a magnetic field then a magnetic field then a magnetic field should induce a current in a conductor. I told them that if we push a north pole of a magnet into the solenoid, there will be a current generated in the coil that sets up its own magnetic field. This magnetic field always opposes the change in magnetic flux in the loop. So if we push a north pole into the solenoid, the flux is increasing and so the current generates a magnetic field to oppose this by having a magnetic field that points out of the solenoid on the same side. I then took my right hand and explained that I need to point my thumb in the direction of the induced magnetic field's north pole which in this case points out of the solenoid. I then put my other fingers around the solenoid and said that these fingers then point in the direction in which the current will flow in the solenoid. After that I then did an example of if the north pole is pulled out of the solenoid and what the direction of the current would be.
Jared	**Did you have learners do any examples on their own where you told them that a particular pole of a magnet is moving either into or out of a solenoid and then learners had to determine the direction of the induced current using the Right Hand Rule?**
Teacher	No. I just did the two examples that I spoke of and had the learners practice the Right Hand Rule while we did them.
Jared	***The CAPS document says to first state Faraday's Law, then show the right hand rule, then introduce magnetic flux, ensure that learners know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux and lastly, calculate the induced EMF and induced current for situations involving changing magnetic fields. Would you introduce these concepts in the same order?***

Teacher	I didn't though. I didn't introduce Faraday's Law and then start with the change in magnetic field and the magnetic flux and all of that. But maybe it will make sense to do that.
Jared	***How did you introduce it?***
Teacher	So I just followed the textbook. So I started with the whole magnetic field and then how sending a current through a wire can induce magnetic field, and then we went the other way round. Moving or changing magnetic field can induce a current. Then from there, I introduced magnetic flux. From magnetic flux, I introduced Faraday's Law. But maybe if you start with introducing Faraday's Law, maybe they will know where this is going and that will maybe help. But I did not do it.
Jared	***Which of those concepts, of those five or six, do you believe is the most pertinent to teaching and understanding and teaching of Faraday's Law?***
Teacher	I think the most important for me…I think it's the magnetic flux part. Because magnetic flux plays such a big role in Faraday's Law. It's because magnetic flux is changing that there's an induced EMF. I would say, yes, the magnetic flux part and the changing of the magnetic field.
Jared	***Did your learners have any difficulties with the concept of flux or its formula?***
Teacher	Some of them struggle with that cosTHETA, the angle. They struggle with that angle, to understand that it's between the normal to the coil and the magnetic field lines. So they see it, if they say that the magnetic field lines are perpendicular to the coil, they tend to use cos90. So it's always a struggle to get them to…I think because they don't understand the concept of normal.
Jared	***How did you address these difficulties with your learners?***
Teacher	I used a coil and the magnetic…so I did a more visual part of asking them, 'So if the coil is like in the perpendicular position to the magnetic field, what is the angle?' So just basically drilling it into them to ask it in this position, what is the angle. In another position, what Is the angle? Because some of them, if they still don't get it, I tell them to go and study if they say the coil is perpendicular to the magnetic field lines, the angle will be zero and if its parallel, its 90.
Jared	***Faraday's law speaks of the rate of change of flux, and not just flux. What about this relationship is important for learners to understand?***
Teacher	First of all that it's the change in magnetic flux. That it's because there's a change in the magnetic field that you get an induced EMF. And how fast this change is happening.
Jared	***Did you up pick that learners had any difficulties regarding any of the concepts regarding Faraday's Law other than you said with the angle?***

Teacher	Not really. We wrote a class test on it afterwards and it was actually one of the better class tests. So what I've seen is the definition, they struggle with the definition. Maybe they just didn't study it.
Jared	***The CAPS document says calculate the induced EMF and the induced current for the situations involving a change in magnetic field. What other factors other than a change in magnetic field could induce and EMF in a solenoid other than magnetic field strength?***
Teacher	So changing the angle of the normal and the magnetic field, so that cosTHETA. Yes, I think that's it.
Jared	***Did you show any practical examples of how each these factors could affect the magnitude of the induced EMF?***
Teacher	I did explain the whole, if you change the number of turns in the coil, how it will influence the EMF, how if you change the magnetic field, how it will influence. And if the time to change the magnetic flux is changed, how it will influence. So I talked about the proportionalities a bit. But we didn't actually do any examples on that.
Jared	***Should learners be expected to do calculations in which the EMF is not due to a change in strength of the magnetic field but due to other factors?***
Teacher	I think so. They can change the angle. But then we didn't do any of those so it's a gap. I'm trying to think now what… the exam guidelines just state use that formula for calculations. They don't say necessarily what needs to be changed.
Jared	***CAPS says to show a practical demonstration. They also list resource materials like a solenoid, bar magnetic, galvanometer and connecting wires. Did you do any demonstrations in any form with learners?***
Teacher	No, no I did not.
Jared	***Was there any reason for that?***
Teacher	I think it is because we are a little bit behind. So I told them they could watch Youtube videos. But I didn't show them the Youtube videos myself.
Jared	***Did you tell which videos to maybe access? Is it anything specific?***
Teacher	Yes I did. I told them channels to go and watch. So there's a Mindset learn. There's one on the tv as well; they know about it. And then I also told them Boseman's Science or something like that. They also have nice simulations to show with that stuff.
Jared	***You spoke of showing learners simulations. Did you show them any simulations in this section?***
Teacher	I didn't, no.
Jared	***Did you do any demonstrations or diagrams in class?***
Teacher	Just that one I did in class on how they came up with the setup of that current is induced.
Jared	***Faraday's experiment?***

Teacher	Yes, that's the only one.
Jared	***In your lesson, just after discussing the experiment conducted by Faraday with iron ring and the coils of wire, you said to the class "Like I said on Thursday, if we have a magnet inside of a coil, it's not going to do anything. It's when we move the magnet out of the coil and into the coil that will induce a current." Had you already dealt with the concept of induction of an EMF by a change in magnetic field before this?***
Teacher	Yes, so they previous lesson we dealt with that whole movement of a magnet into and out of the coil and then using the right hand rule to see where the current will be induced in the wire.
Jared	***Alright. And then CAPS says use the right hand rule to determine the direction of the induced current in the solenoid when the north and the south pole of the magnet is inserted or pulled out. The direction of the current and associated magnetic field can all be found using only using 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. You say you did show this to learners?***
Teacher	Yes.
Jared	***Next thing, what is the concept of Lez's Law?***
Teacher	I don't know to be honest. No. I just know that on a video that I watched, they said that the negative of Faraday's Law, that part where it's negative N delta phi over delta t, that negative is explained through Lenz's Law. But I actually have no clue.
Jared	***The CAPS document does not mentions the words "Lenz's Law". Did you introduce this concept to the learners?***
Teacher	Not the concept. I told them that if they go further in Physics at university they will do Lenz's Law and Len's Law explains that negative. It's just because some learners tend to be interested more and then they want to know more, and then other are not interested. So no, I did not. I was scared it was going to confuse them.
Jared	***Are learners ever tested on Lenz's Law?***
Teacher	No, I don't think so. No
Jared	***And then, after having taught the topic of Faraday's Law, is there anything that you would change about the way that you taught it?***
Teacher	If I have more time I would like to show them more videos of the whole setup and how the current is induced and all of that, but with time limits I think that's the only thing.
Jared	***I know you said you were behind on schedule this year but with regards to just the amount of time given to Faraday's Law and maybe electromagnetism, do you feel it is enough for that topic?***

Teacher	Overall three hours if you have a look at the CAPS, yes I would say it's enough.
Jared	***OK, based on your first key idea, Magnetic Fields, what do you feel needs to have been taught to learners before they are dealing with magnetic fields? What knowledge should they already have?***
Teacher	Um, before we do now Faraday's law?
Jared	***Yes.***
Teacher	I talk about the fact of magnetic fields there. Just the basics of magnetic fields like direction of the magnetic field. They have to know where the magnetic field is coming from; there must be a magnet first of all. Then we can on to the fact that we can create a magnetic field through the current that's running through the wire. Not just the basics like what is a magnetic field, how does it look around a magnet?
Jared	***Is your key idea A basically of what they learnt in grade 10 and you revising it?***
Teacher	Yes.
Jared	***And is it something you revised when you started this section? Did you just remind them of the properties of magnetic fields or drawing any pictures or anything like that?***
Teacher	I just recapped with the…I just asked them what they know, what can you remember of magnetic fields and then I just filled in whatever they did not get to. But just basically what we did in grade 10…
Jared	***Can you remember if you did any pictures or representations or maybe just stated what the properties are?***
Teacher	I think I just stated. I don't think I drew anything on the board.
Jared	***If you think in terms of magnetic flux, what would learners have to know before they are introduced to that idea?***
Teacher	Before being introduced to magnetic flux, I think just the different components of the formula. Like we discussed magnetic fields and just discussing again the area.
Jared	***How would you plan to explain magnetic flux if you were teaching it.***
Teacher	So I use that whole…
Jared	***That wooden coil?***
Teacher	Yes, that wooden thing. So what I do is, I use that to explain the magnetic flux as the…I simplify it for them, I don't know if it's right but it's the…you can actually say it's the amount of magnetic field lines that's going through the coil. So when it's in a perpendicular position, all the field lines are going through so you're going to have the maximum magnetic flux. And then as you turn it, as soon as it's parallel to the field lines, there's none of the magnetic field lines going through the coil. That's why the magnetic flux through the coil is zero then. And then if they understand that concept, then you can go on to the whole angle between the

	normal and the surface of the coil to the magnetic field to explain that cosTHETA. Otherwise they struggle with that part if you just throw them with the cosTHETA they just freak out. So I usually just explain in the simple terms how many magnetic field lines are through. So we do something simple like there's 5 magnetic field lines like that going through. Like if I turn it now its 4, 3, 2, 1 and then 0.
Jared	***What made you specifically select these key ideas for Faraday's law?***
Teacher	I think just because, if you look at the formula used for Faraday's law that is the major components of Faraday's law with the change in the magnetic field. That there cannot be an induced emf unless the flux is not changing. So I just think it's the main components for Faraday's formula.
Jared	**What are typical learner misconceptions either concerning you key ideas and / or Faraday's law?**
Teacher	I think the major, major one is the whole angle. So they forget or they don't understand that it's the angle to the normal to the surface of the coil and the magnetic field lines. So when you say that the coil is perpendicular in the magnetic fields lines, it confuses them because then they want to use cos90. Or when you talk about parallel, they want to use zero. I think that's maybe the biggest problem there.
Jared	***Anything to do with Faraday's law itself, maybe the law or the formula or the calculations?***
Teacher	Not that I can think of now. Maybe after I've marked the papers.
Jared	***Basically your teaching strategy, if you think of how you would teach it is just to recap the idea of magnetic field from grade 10. How would you go about teaching magnetic flux if you think of maybe representations you'll use? You told me already with the coil. Is there anything else specifically that you focus on other than the angle?***
Teacher	No not really. I introduce them to the formula and we take it from there. I give them the formula for magnetic flux and we break it up into the different parts; what's the B, what's the A, what's the cosTHETA.
Jared	**How do you link the idea of flux to a change in flux? Is there anything else learners need to understand about that change in flux?**
Teacher	Well the change in magnetic flux is what is causing the emf. So I show them that if you just have the coil in the magnetic field, there's nothing going to happen, there's no emf. But as soon as you're turning the coil in the magnetic field or moving it out of the magnetic field and into the magnetic field, that's when you have the emf. So if you think of Faraday's law, Faraday's law says that it's the change in magnetic flux that's causing the induced emf. So we have magnetic flux, but if it's not changing, it cannot induce an emf.

Jared	***And if you think in terms of teaching Faraday's law, once you've taught the change in flux, is there anything else that you focus on about Faraday's law?***
Teacher	Ummm…
Jared	***Do you tell them maybe about different ways to change the flux?***
Teacher	Ja (Yes), so we discuss the different types. So we discuss moving into and into and out of the field, or just turning it in the field. That's basically the two options that you have. Or going from a certain magnetic field strength into another magnetic field strength. So we discuss that and then again just the formula. How dies time, the change or the time that it takes to change the magnetic flux influence the emf and what will give us a bigger change emf with the change in magnetic flux and the windings and that influences the emf.
Jared	***Is Lenz's law part of Grade 11 electromagnetism?***
Teacher	I think in the CAPS document they state something about Lenz's law.
Jared	***Did you show learners anything about Lenz's law?***
Teacher	No. I mentioned it, but no.
Jared	***Have you ever come across that it's being asked?***
Teacher	No. I think it's with the whole explanation, in the CAPS document they say you have to do an experiment just to bring it all together. But I haven't done that.
Jared	***What is the concept of Lenz's law?***
Teacher	I remember something, let me just think. No, I have no idea. I know it's there. Isn't it with the direction or something? No I don't know.
Jared	***What is your qualification?***
Teacher	BSc. It's a very weird, it's called BSc Ed. So I had chemistry up until third year and calculus and algebra until second year. Physics only until first year. Then I did PGCE.
Jared	***What resources did you use to plan your lesson?***
Teacher	The textbook DocScientia and then I looked at the exam guidelines at what learners can be asked and YouTube videos but for me to understand.
Jared	***Did you look at the videos because you knew I was going to observe or not?***
Teacher	No, it's a yearly thing because I know because this is not my strong point.
Jared	***It says in the CAPS document to use words and pictures to describe what happens to a bar magnet when pushed into or pulled out of a solenoid connected to a galvanometer. Is there anything that learners should already know, knowledge that they should already know before showing this and explaining what it is?***
Teacher	Well I'm guessing they should know what a galvanometer is. I think they should just know moving this magnetic with induce a current. But, OK it shown with the galvanometer so they don't have to necessarily know that.

Jared	***Maybe prior knowledge if you think you're going to explain this demonstration. Is there something that they have to understand or should understand?***
Teacher	Ummm, no.
Jared	***What are they trying to indicate with this?***
Teacher	With this is the movement of the bar magnetic within the solenoid can induce a current in the wires, or across the end of the wires. So maybe again like the magnetic fields, they should know something about that.
Jared	***You have said the difficulties regarding magnetic flux. There's nothing else you can identify other than the difficulties with the angle?***
Teacher	I think sometimes the math is the problem as well. They struggle with the…the reading is more the problem. Sometimes we give them the side of…we say it's a square coil and we give them a side length and other times we give them the area. So some of them are unsure when to use the area as is or when to calculate the area. But that I think is a reading problem.
Jared	***Was this difficulty something you picked up while you were teaching your lesson or had you planned for it before you taught?***
Teacher	No when we marked the homework.
Jared	***You picked up they were struggling?***
Teacher	Yes because some of them said they calculated the area but for that question I gave them the area.
Jared	***Can you think of difficulties or misconceptions you had in mind that you specifically planned to address in your lesson?***
Teacher	I think it's just the angle, because I know every year that a big problem.
Jared	***CAPS says use the right hand rule to determine the direction of the induced current induced in a solenoid when the north or south pole is inserted or pulled out. Did you show this to learners?***
Teacher	Yes, we did that.
Jared	***You don't mention the right hand rule in you document. Is there a specific reason for that?***
Teacher	No.
Jared	***Does it relate to Faraday's law?***
Teacher	With the calculation, I would say most of the time they don't use the right hand rule. So in question papers that's usually two separate questions. First ask them to use the right hand rule with the setup and then they use another question for Faraday's law. And I think that's why I didn't actually put that in my document.
Jared	***Why should learners have to be taught the right hand rule to determine the direction of the induced current?***

Teacher	I think if you go further with this, the motors and the generators, I think that comes more into play with that. So they have to understand that it goes in a certain direction and the motors and generators, it's more prominent. I don't know.
Jared	***So at school level?***
Teacher	Yes, grade 12.
Jared	**CAPS says, know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux passing defined as the phi equals BA cosTHETA where theta is the angle between the magnetic field B and the normal of the area A. Regarding that point there, this statement is broad and mostly indicates that learners should know the equation for magnetic flux. Is showing the equation and explaining the variables in the statement sufficient for teaching magnetic flux?**
Teacher	Ummm…
Jared	**Is it expecting any more of you?**
Teacher	I don't you can only do that, only show them the formula and expect them to understand the whole magnetic flux part. But like t I said, we usually look at the formula and we look at the variables. Ya, I don't know.
Jared	***CAPS say know that the induced current flows in a direction to set up a magnetic field that opposes the change in magnetic flux. Did you show this to learners?***
Teacher	I don't think so. No I didn't.
Jared	***Is it discussed any way in the work schedule?***
Teacher	No, I have no idea.
Jared	***CAPS document says calculate the induced emf and induced current for situations involving a changing magnetic field. Again this is broad and mostly indicates that learners should know the equation to calculate induced emf. Is showing learners the equation and explaining the variables sufficient for teaching learners about Faraday's law?***
Teacher	Again I think it's necessary. But I think it's necessary to do all the different examples that they might come across in the exams. So showing the formula, looking at the variables and applying that through examples through different types, only changing the magnetic field or changing the time you are changing the magnetic flux.
Jared	***CAPS document says to show a practical demonstration. They also list resources material: a solenoid, bar magnetic, galvanometer, connecting wires. How would you use these apparatus to perform a demonstration?***
Teacher	Well I think that would only be to show that moving a bar magnet into and out of a solenoid can induce a current. So with that, they can see that the galvanometer is deflecting from the middle. And I think with that they can actually see that if you

	are pushing the magnet in, it goes to one side, and if you are pulling it out it goes to the other side. And if there's no movement, the galvanometer will be zero. But we didn't do it.
Jared	***The practice questions that you selected for learners, did you do questions after teaching magnetic flux and then you first do questions or did you practice. Or did you practice at the end of teaching electromagnetism?***
Teacher	No I think after magnetic flux we did some questions and then based on that we did faraday's law and there was another exercise that we split it.
Jared	***Did you do exercises in the book or were there questions that you selected?***
Teacher	The book. So what I do is, I look at the exercise and I do one or two with them as a class example and then the rest will be homework and them we mark it.
Jared	***Is there anything specifically that you look for when selecting questions?***
Teacher	I'm trying not to pick the most difficult ones because they have to think a little bit but I'm trying to do different…like in one they calculate the magnetic flux and then in another one maybe they give the magnetic flux but ask for the magnetic field strength. So I'm trying to do different calculations of the same thing so they can see how you to use it differently.
Jared	***Back to the previous point on calculating the current. How can you calculate the current that's induced?***
Teacher	If you have the emf then you have to use your circuit knowledge. Usually they have to use V = I.R so Ohm's law.
Jared	***Did you show that to learners?***
Teacher	Yes we did examples like that
Jared	***Was it something you taught separately or sort of just spoke of it when it came in the exercise?***
Teacher	When it came in the exercise. So when they asked calculate the current, I asked the learners how do you calculate the current. Because usually they give you the resistor of something in the circuit and you've just calculated the emf. I wanted them to come up with the whole idea of using circuits. Some of them did. I did not teach that separately.

END

LINDA - POST-INTERVIEW (SCHOOL 2)	
Jared	***How many years have you been teaching?***
Teacher	25
Jared	***How many years have you been teaching grade 11 Physical Science?***
Teacher	19
Jared	***Have you read these pages in the CAPS document regarding Faraday's law?***
Teacher	Yes.
Jared	***Did you go through these pages when planning and preparing for your lesson on Faraday's law?***
Teacher	No, honestly I did not.
Jared	***What did you use to plan your lesson?***
Teacher	The textbook, my previous experience with this topic, and another textbook as well. Olivier's books.
Jared	***What topic is taught before Faraday's law or electromagnetism in the grade 11 syllabus?***
Teacher	Static electricity and electric fields.
Jared	***What is taught after this section?***
Teacher	Current electricity?
Jared	***Are there any topics in the grade 10, 11 or 12 syllabus that influence this topic and the way in which you teach it?***
Teacher	Yes, especially the grade 12 syllabus in terms of motors and generators. Grade 10, not so much because the magnetism that they do there is on a very basic level.
Jared	***What do you understand from the CAPS document's statement to state Faraday's law?***
Teacher	They have to be able to define Faraday's law. To be able to state the law.
Jared	**CAPS says use words and pictures to describe what happens when a bar magnet is pushed into and pulled out of a solenoid connected to a galvanometer. How would you describe what happens when a bar magnet is pushed into and pulled out of a solenoid connected to a galvanometer in words for learners?**

Teacher	In words, when you move it in or out, then the galvanometer will change, there will be a reading on the galvanometer. The needle will deviate in one direction if you push it in, and in the other direction if you pull it out.
Jared	***Did you explain this to learners during your lesson?***
Teacher	No I didn't. What bothers me is that we haven't got a galvanometer. I've never seen one in the 25 years that I've been teaching. I don't know if they are even available. It bothers me that you need to describe it in terms of apparatus that we don't have.
Jared	***Did you use picture or other representations to explain what the curriculum expects in terms of showing a magnet being pushed into or pulled out of a solenoid?***
Teacher	Yes. There were pictures of that in the textbook and I explained it to learners in words.
Jared	***The CAPS document says to first state Faraday's Law, then show the right hand rule, then introduce magnetic flux, ensure that learners know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux and lastly, calculate the induced EMF and induced current for situations involving changing magnetic fields. Would you introduce these concepts in the same order?***
Teacher	I would, I think that exactly what I did. I gave them an overview of Faraday's law. They haven't got a clue what it means. Then you break it down. I did start with the RHR. And then I spent a lot of time on magnetic flux because it's a totally new online concept to them. And then I went back to Faraday's law which makes more sense to them. And then we moved on to actually calculating the induced emf.
Jared	***Which of these four points is the most important for the understanding of Faraday's law?***
Teacher	I think the concept of the magnetic flux.
Jared	***Why would you say that?***
Teacher	Because it's one of the essential quantities in Faraday's law and the equation. So if they haven't got the concepts of the magnetic flux, they don't know what to substitute into the formula or where to get the values from.

Jared	***Based on the CoRe that you completed, you spoke of introducing magnetic flux before Faraday's law but in your lesson you first showed learners Faraday's equation and stated the law. Is there any reason for changing the order around?***
Teacher	I want them to know where they are going to. They need to see why we are discussing what we are. To me it feels like they are blind. If they just start with magnetic flux, they wouldn't understand why we are going to do it. So I showed them the law, then introduced the different concepts then put it back together again.
Jared	***You discussed the concept of magnetic flux density. This term does not appear in the CAPS document. What was your reason for explaining this?***
Teacher	Actually the CAPS document doesn't use the words 'magnetic field strength' either. They just talk about the magnetic field B. But what do you mean by the magnetic field. So I felt that learners don't realise that B is something they know. They've known the magnetic field from grade 10 where you indicate it with field line. They have the concept of strength because that is what the grade 10 document puts emphasis on; where you have fewer lines it's weaker and where you have more lines it's strong. So I wanted to define the magnetic field in more detail to them so that they understand what B is. And then I felt that they get confused with the magnetic flux density and the magnetic flux. Because it not actually the same concept. The one is B and the other is B times A.
Jared	***Did your learners have any difficulties with the flux or the formula?***
Teacher	No, I think they grasped it pretty well.
Jared	***Faraday's law speaks of the rate of change of flux with the word 'flux' italicised for emphasis. Why do you think this particular word is emphasised by the curriculum.***
Teacher	Well it's stressing that specifically flux needs to change over time for an emf to be induced, not just the magnetic field but specifically the field that is passing through the conductor.
Jared	***Did you pick up if learners had any difficulty with any of the concepts taught regarding Faraday's law?***

Teacher	Yes, they struggled tremendously with the angle between the magnetic field and the normal. They still struggle with that. So I need to still give them additional exercises.
Jared	***The CAPS document says to show a practical demonstration of Faraday's law. It provides a list of apparatus. Did you do any sort of representation of Faraday's law?***
Teacher	Apart from a YouTube video, no because as I said, we don't even have a galvanometer.
Jared	***What is the concept of Lenz's law?***
Teacher	That the direction of the field will oppose the inducing action. So if you try to push in a north pole, a northpole ill form at that side to repel it. If you try to pull out the north pole, the polarity on that side will be south to prevent it from moving out.
Jared	***Did you introduce this concept to learners?***
Teacher	Yes, the following day.
Jared	***Does the CAPS document in any way reference Lenz's law?***
Teacher	No, but it's one of those things that the textbook shows it so you discuss it with learners.
Jared	***For question 7 and your key idea of induced emf, you said that learners must be able to do calculations and must be able to interpret questions. How would you say this influenced the way that you planned your lesson or how you taught it?***
Teacher	I did questions at the end but again I did not have time to do enough. I wanted to give them more time but I never had the opportunity to revisit the topic because the year was just too short. The ATP of the department doesn't correspond to the exam timetables that they eventually give out to us because I thought in the 4th term I have four weeks to still teach and I would have time to revisit the topic but when the common exam timetable came out, we realised our four weeks was down to two and a half weeks.
Jared	***The questions that you did, was that on both magnetic flux and emf at the end?***
Teacher	No, it was in the end just the induced emf, just Faraday's law and it was only one or two problems…what was available in the textbook. I did not get the

	opportunity to give them additional exercises. Although I have additional exercises from other textbooks, I did not have the time to administer them.
Jared	***Did you do any questions solely on magnetic flux?***
Teacher	No nothing, it was just on the emf where they had to use Faraday's law.
Jared	***Your idea of: The effect of magnetic field on current, does that in anyway relate to Faraday's law?***
Teacher	It does because you get an induced emf because the conductor is moving in the field, there's an emf induced.
Jared	***When you did the demonstration with the torch to show the induction of an emf, what all did you want learners to see other than an induction of an emf? Was there anything else?***
Teacher	I wanted them to first understand the idea of induction. The fact that if it's stationary and if there's no movement, then there's nothing. But the moment there's motion then you get, well the induced emf which you can't see but you can see the result, the fact that the LED bulb lit up. I wanted them to realise that there's only emf if there's movement, if there's no relative movement between the conductor and the magnetic field, then nothing happens. It is the change in the flux that causes the emf.
Jared	***Can you think of any ways that while you are teaching your lesson, you are thinking this is how I am determining whether learners are still understanding or not? Is it certain questions that you think of asking them, is it certain examples you give them? How do you go through your lesson keeping track of whether your learners still understand?***
Teacher	I try to keep track of whether they comprehend from the answer that I receive when I ask them questions or the questions that they ask but in retrospect if I did it again, I've put a lot of content into one period and it was basically a lecture. I wanted them to understand the concept from the beginning to the end so there wasn't enough time for interaction. If I have time I would like to break it down into smaller pieces and give them a question on every aspect and see whether they can cope with that before I proceed to the next concept.

Jared	***The lesson I observed, you started with magnetic flux and then you started with Faraday's law. What had you done in the previous lesson on Electromagnetism? Or had you started…***
Teacher	No nothing. That was the day I started. There was no background whatsoever.
Jared	***The CAPS document says describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer. Is there any knowledge that learners should already have before showing this demonstration to learners?***
Teacher	They should already know the shape of a magnetic field and they should know the Right Hand Rule otherwise they don't understand that concept. I think I've also mentioned it before, Lenz's law, they never mention that anywhere prior. It's too many new concepts that's introduced there. What does the CAPS document means when it says "describe what happens"? What do you observe, what do you see? You will just see the needle of the galvanometer deflecting, but what does that tell the child?
Jared	***What would you explain about that if you were performing the demonstration?***
Teacher	Well first of all I cannot demonstrate it because I do not have a galvanometer that's why I was using the torch. I was trying to make what happens there visual for them so that they can physically observe it.
Jared	***If you had a simulation that you could show them, what about the galvanometer would you show them? If you had all the apparatus. Is there something different you would want to show them?***
Teacher	No, I mean they will see that something is happening, the needle is deflecting if you are pushing it in or pulling it out and standing still. But I also couldn't find a simulation on the internet, a good simulation of this. Not at all.
Jared	***CAPS says use the Right Hand Rule to determine the direction of the induced current when the north pole of a magnet is inserted or pulled out of a solenoid. You did not mention the Right Hand Rule in your CoRe. Is there any reason for that?***
Teacher	No, I think I just forgot about that.

Jared	***What is the purpose of showing learners the Right Hand Rule and determining the direction of the induced current? Why would we expect learners to know the direction in which current is induced?***
Teacher	I honestly don't know what to answer you. I would think the purpose of the Right Hand Rule is for them to understand the concept of induction, the fact that you have a magnetic field that is changing but the magnetic field is changing because the current direction is changing or the other way around. The current direction is changing and therefore the magnetic field is changing. So it comes down to understanding the concept of induction. Induction would not make sense to you if you do not understand that there is a change so I think the purpose of the rule is to understand the change that is happening. Why is the current changing direction? Because you are pulling or pushing the magnet out. If you can't apply the Right Hand Rule, then you can't grasp the concept that the current is and therefore the magnetic field is changing direction.
Jared	***CAPS says "Know that for a loop of area A in the presence of a uniform magnetic field B, The magnetic flux passing through the loop…". This statement is quite broad indicating that learners should know the equation for magnetic flux. Would you say that just showing the formula and stating what the different variables are is sufficient for teaching magnetic flux?***
Teacher	No I don't think it's sufficient because that is exactly what I meant. I want learners to be introduced to that concept earlier in grade 10 where they can start calculating just magnetic flux for different situations. Or if you then keep to this in grade 11, you have to have more time allocated for that because that is exactly what the learners did not grasps because the magnetic field can change, the area can change, THETA can change. And we did not have enough time to look at each situation where one of those factors are changing independently from each other.
Jared	***CAPS says: "Know the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux". Did you show that to learners as well as how to apply the Right Hand Rule?***
Teacher	Yes, I did.

Jared	***Is there any reason you didn't mention in the documents? Do you feel it relates to Faraday's law in any way?***
Teacher	No, that relates to Lenz's law.
Jared	***CAPS says: "Calculate the induced emf and induced current for situations involving a changing magnetic field". Again that is quite broad to just calculate it. Would that be sufficient to have learners only calculate the emf and the current?***
Teacher	I don't know if it's sufficient but that is all we did because that is all that CAPS requires. Actually we just calculated emf. Did we calculate the current? We don't calculate the current. I think current as a whole is neglected because when we were at school, we had to calculate the full force exerted by two current-carrying conductors. That isn't taught to kids anymore.
Jared	***The CAPS document does not mention Lenz's law. Does Faraday's law or the formula in anyway reference Lenz's law or is it a separate concept?***
Teacher	No it doesn't.
Jared	***Should learners be taught Lenz's law in grade 11? Is it expected of you?***
Teacher	Not by the CAPS document. But I feel that it is necessary.
Jared	***Did you teach anything on Lenz's law?***
Teacher	I just mentioned it and tried to explain it to them and referred them to the textbook where the textbook also just mentions it. It is not required that they state the law or they go into in depth. So you mention it but not much more than that. They are not required to state the law. I see now the CAPS document says use Faraday's law to calculate the induced emf and the induced current. How do you use Faraday's law to calculate the induced current? What do they mean by that? If you calculate current, you get an answer of ampere. Meaning that you use induced emf over a resistor or something? Must you relate it to the physical use of a motor in a circuit? I don't know because we definitely didn't go into that. This topic is still a tricky one.
Jared	**You mentioned that you briefly discussed Lenz' law with learners and referred them to their textbooks to where it is discussed. Did you, in**

	your lesson after Faraday's law, teach learners how to determine the direction of the induced current in a conductor using the Right-Hand Rule?
Teacher	Yes. The Right-Hand Rule was taught in the section of current-carrying conductors, before Faraday's law.
Jared	***After having taught the topic of Faraday's law, is there anything that you would do differently the next time you teach it?***
Teacher	Yes, I think I will make more of an effort to find a solenoid and a galvanometer to show them that. Or if I can't acquire a galvanometer, I'll look for a YouTube video that actually illustrates that.
	END

Appendix VI: GDE letter

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE RESEARCH APPROVAL LETTER

Date:	**15 July 2019**
Validity of Research Approval:	**04 February 2019 – 30 September 2019** **2019/148**
Name of Researcher:	**Mitchell J**
Address of Researcher:	**87 Oukraal Apartments**
	1 Oukraal Boulevard, Silver Lakes
	Pretoria, 0081
Telephone Number:	**012 807 3423/ 0833 577 962**
Email address:	**jaredmitchell@hotmail.com**
Research Topic:	**Understanding teachers' interpretation of Faraday's Law in terms of their Pedagogical Content Knowledge.**
Type of qualification	**Maters in Education**
Number and type of schools:	**Four Secondary Schools**
District/s/HO	**Tshwane South**

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.

The following conditions apply to GDE research. The researcher may proceed with the above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

15/07/2019

1

Making education a societal priority

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

1. *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 outline 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. If incomplete, an amended Research Approval letter may be requested to conduct research in the following 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/s must supply the Director: Knowledge Management & Research with one Hard Cover bound and an electronic copy of the research.*
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

....

Mr Gumani Mukatuni
Acting CES: Education Research and Knowledge Management

DATE: 15/07/2019

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

Appendix VII: Principal letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Department of Science, Mathematics and Technology Education
Groenkloof campus
Pretoria 0002
Republic of South Africa
Tel: +27 124205967
Ernest.mazibe@up.ac.za

Dear principal,

REQUEST FOR PERMISSION TO CONDUCT A RESEARCH AT YOUR SCHOOL.

I am a student in the Department of Science, Mathematics and Technology Education at the University of Pretoria, doing a research study entitled "**Understanding teachers' interpretation of the curriculum on Faraday's Law in terms of their PCK**". I am requesting for permission to collect data at your school.

Through this study I wish to determine:

How teachers' interpretation of the curriculum on Faraday's Law can be understood in terms of their Pedagogical Content Knowledge?

As part of the study I would like to collect data throughout the instructional practice processes of two willing science teachers. I wish to gather voice and video recording and documentation as the teachers plan their lessons and present the lessons. After they have presented their lessons, the teachers will be requested to answer a few questions during an individual interview that will prompt them to think about actions while they planned and presented their lessons. This data will be used for analysis purposes only if permission is granted. This data will assist me as I attempt to answer the research question stated above. Findings of such a study have the potential of informing the design of better and more engaging science lessons for future presentations. Should you agree, please read and sign the attached consent form. Thank you very much for spending time to consider this request.

Kind regards.

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Signed: .... Date..................

Informed consent form for data collection

Please read the conditions below and sign if you agree that your school may participate.

With reference to the request for permission to conduct research entitled: **Understanding teacher's interpretation of the curriculum on Faraday's Law in terms of their PCK**, I understand and agree that:

1. Two willing science teachers at my school will participate in the study.
2. The two teachers shall be audio and video recorded as they plan and present their lessons.
3. The two teachers will participate in follow-up semi structured interviews which will also be audio recorded.
4. Data collected will only be used for research purposes.
5. The identity of the school, educators and learners will be held in the strictest of confidence.
6. This school's participation in the project is voluntary, and the school can withdraw at any stage of the research.
7. All data collected with public funding may be made available in an open repository for public and scientific use.
8. I am not waiving any human or legal rights by agreeing to participate in this study.
9. I verify by signing below that I have read and understood the conditions listed above.

If you have any questions about this research project, please contact Mr. J. Mitchell (researcher) by telephone on 083 357 7962 or email jmitchell@willowridge.co.za

School's name and stamp: ....

Principal's name: ....

Signature.. Place and date: ....

Researcher's name: Mr. J Mitchell

Signature: .... Place and date:

Appendix VIII: Teacher letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

CONSENT FORM

I, ____ understand that:

1. The purpose of this study is to capture and analyse teacher discourse, written planning, lesson presentation and lesson reflection for analysis of the teacher's interpretation of the curriculum on Faraday's Law in terms of their pedagogical content knowledge.
2. Lesson plan documentation, audio and video recordings will be used to capture all activities.
3. As part of this study I will have to participate in more than one activity, i.e. planning of a lesson, presentation of a lesson and answer questions that will encourage me to think about my pedagogical content knowledge on Faraday's Law, as well as my actions while presenting the lesson.
4. Any personal information about me that is collected during the study will be held in the strictest confidence.
5. I am not waiving any human or legal rights by agreeing to participate in this study.
6. All data collected with public funding may be made available in an open repository for public and scientific use.
7. My participation in this study is completely voluntary and I may withdraw participation if I decide to do so at any time during the study.

I verify, by signing below, that I have read and understand the conditions listed above.

Signature : ____

Date : _________________________

PLEASE COMPLETE FIELDS ON THE NEXT PAGE

PARTICIPATION IN INTERVIEW BEFORE LESSON PRESENTATION

To capture your pedagogical content knowledge as you plan your lesson, you will be interviewed before you present your lesson on Faraday's Law. Please indicate below with a tick in the appropriate box, whether or not you would be willing to be interviewed before you present your lesson.

Yes	
No	

VIDEO RECORDING DURING LESSON PRESENTATION

To capture the presentation of your lesson, you will be asked to be video recorded while you present your lesson. Please indicate below with a tick in the appropriate box, whether or not you would be willing to be video recorded while you present your lesson.

Yes	
No	

PARTICIPATION IN INTERVIEW AFTER LESSON PRESENTATION

To enrich the process of data collection, additional data by way of interviews after you have taught your lesson will be necessary. Please indicate below with a tick in the appropriate box, whether or not you would be willing to be interviewed at the end of the lesson you presented.

Yes	
No	

Appendix IX: Parent/guardian letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Department of Science, Mathematics and Technology Education
Groenkloof campus
Pretoria 0002
Republic of South Africa
Tel: +27 124205967
Ernest.mazibe@up.ac.za

Dear parent/guardian,

REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN YOUR CHILD'S CLASSROOM

I am a student in the Department of Science, Mathematics and Technology Education at the University of Pretoria, doing a research study entitled "**Understanding teachers' interpretation of the curriculum on Faraday's Law in terms of their PCK**". I am requesting for permission to collect data during a lesson presented to your child. Through this study I wish to determine:

How can a teachers' interpretation of the curriculum on Faraday's Law be understood in terms of their PCK?

As part of the study I would like to sit in on the lessons attended by your child and observe the teacher as he/she delivers their lesson on Faraday's Law. To enable me to accurately capture the lesson as it is executed I will need to video record the lesson. I wish to however, assure you as the parent/guardian that the recorder will be focused on the teacher at all times. In instances where the learners are captured as a result of the teacher engaging with them during the lesson, these clips will be deleted and only the audio will be used to jog the memory of the researcher about the actual occurrences of the day. Your child will be part of this lesson only if permission is granted.

This data will assist me as I attempt to answer the research question stated above. Findings of such a study have the potential of informing the design of better and more engaging science lessons for future presentations. Should you agree, please read and sign the attached consent form. Thank you very much for spending time to consider this request.

Kind regards

Signed: .... Date...................

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Informed consent form for data collection

Please read the conditions below and sign if you agree that your child may participate.

With reference to the request for permission to conduct research entitled: Metacognition underlying instructional practice of high school science teachers, I understand and agree that:

My child's science teacher will participate in the study.
The teacher shall be video recorded as he/she presents a lesson.
Data collected will only be used for research purposes.
The identity of the school, educators and learners will be held in the strictest confidence.
My child's participation in the project is voluntary, and the child can withdraw at any stage of the research.
I am not waiving any human or legal rights by allowing my child to participate in this study.
All data collected with public funding may be made available in an open repository for public and scientific use.
I verify by signing below that I have read and understood the conditions listed above.

If you have any questions about this research project, please contact Mr. J. Mitchell (researcher) by email on jmitchell@willowridge.co.za

Child's name and surname: ....

Parent/Guardian's name and surname: ....

Signature.. Place and date: ....

Researcher's name: Mr. J. Mitchell

Signature: .... Place and date: ………………………………

Appendix X: Learner letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Department of Science, Mathematics and Technology Education
Groenkloof campus
Pretoria 0002
Republic of South Africa
Tel: +27 124205967
Ernest.mazibe@up.ac.za

Dear learner,

REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN YOUR CLASSROOM

I am a research student in the Department of Science, Mathematics and Technology Education at the University of Pretoria, doing a research study entitled "**Understanding teachers' interpretation of the curriculum on Faraday's Law in terms of their PCK**". I am requesting for permission to collect data during a lesson attended by you at your school. Through this study I wish to determine the Pedagogical Content Knowledge held by teachers in the topic of Faraday's Law as the plan for, present and reflect on their lesson.

As part of the study I would like to sit in one of the lessons attended by you and observe the teacher as he/she delivers the lesson. To enable me to accurately capture the lesson as it is given I will need to video record the lesson. I wish to however, assure you that the recorder will be focused on the teacher at all times. In instances where you are captured as a result of the teacher engaging with you during the lesson, these clips will be deleted and only the audio will be used to jog the memory of the researcher about the actual occurrences of the day. You will be part of this lesson only if permission is granted by yourself and your parents/guardian.

This data will assist me as I attempt to answer the research question stated above. Findings of such a study have the potential of informing the design of better and more engaging science lessons for future presentations. Should you agree, please read and sign the attached consent form. Thank you very much for spending time to consider this request.

Kind regards

Signed: .... Date..................

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Informed consent form for data collection

Please read the conditions below and sign if you agree to participate.

With reference to the request for permission to conduct research entitled: **Understanding teachers' interpretation of the curriculum on Faraday's Law in terms of their PCK**, I understand and agree that:

My science teacher will participate in the study.
The teacher shall be video recorded as he/she presents a lesson.
Data collected will only be used for research purposes.
The identity of the school, educators and learners will be held in the strictest confidence.
My participation in the project is voluntary, and I may withdraw at any stage of the research.
I am not waiving any human or legal rights by agreeing to participate in this study.
All data collected with public funding may be made available in an open repository for public and scientific use.
I verify by signing below that I have read and understood the conditions listed above.

If you have any questions about this research project, please contact Mr. J. Mitchell (researcher) by e-mail on jmitchell@willowridge.co.za

Learner's name and surname: ....

Signature...   Place and date: ....

Researcher's name: Mr. J. Mitchell

Signature: ....   Place and date: ………………………………