Teachers’ pedagogical content knowledge and learners’ performance in electromagnetic induction following a generic intervention.

LISTER MUNODAWAFA DZIKITI

Submitted in fulfilment of the requirements for the degree

PHILOSOPHIAE DOCTOR (PhD)

in the
Faculty of Education
UNIVERSITY OF PRETORIA

Supervisor: Prof Estelle Gaigher
Co-supervisor: Dr Corene Coetzee

OCTOBER 2023

DECLARATION OF ORIGINALITY

I, LISTER MUNODAWAFA DZIKITI, declare that "*Teacher's pedagogical content knowledge and learners' performance in electromagnetic induction following a generic intervention*" which I hereby submit for the degree **PHILOSOPHIAE DOCTOR** at the University of Pretoria, is research work of my own originality and that any material from other sources, articles and texts that I have utilised or quoted have been acknowledged by means of complete referencing.

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DEPARTMENT	Science Mathematics and Technology Education
APPROVAL TO COMMENCE STUDY	25 May 2021
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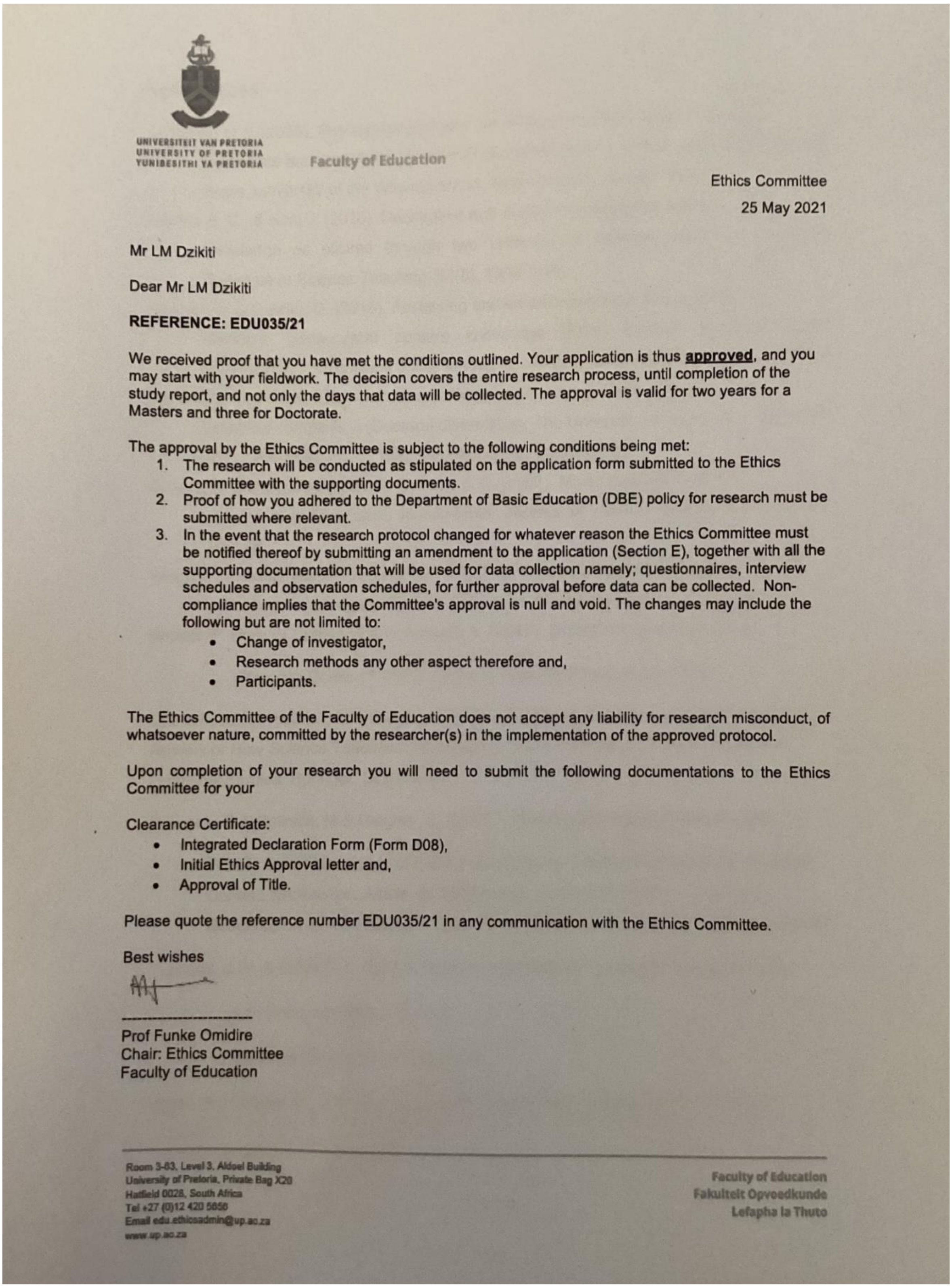

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ABSTRACT

This study investigated the effect of a generic intervention on in-service teachers' pedagogical content knowledge (PCK) and on their learners' performance in Grade 11 electromagnetic induction (EMI). The sub-topic of EMI was selected as it received little attention in the literature.

The conceptual framework was adapted from the refined consensus model for PCK, viewing the intervention as knowledge flow from collective PCK to personal and enacted PCK, enhancing learner outcomes.

The research problem required a pragmatic perspective, using a mixed methods case study approach with teachers' PCK constituting qualitative data while learner performance provided quantitative data in a two-group, baseline-test / post-test design. Eight schools were conveniently selected to participate in the study.

PCK data was collected from the four teachers in the treatment group before and after the intervention to track the development of their PCK in EMI. Several data collection instruments were used. A standard PCK instrument, the CoRe tool, was applied before and after the intervention. Furthermore, video-recorded lesson observations, video-stimulated recall interviews and a semi-structured interview were used to assess PCK development.

A total of 411 Grade 11 Physical Sciences learners from the treatment and control groups wrote a baseline test on a previously completed Grade 11 topic before the intervention. A post-test on EMI was written after the teaching of the topic EMI was completed. The Mann-Whitney test, conducted at a 5% level of significance, showed that there was no significant difference between the groups' performance prior to the intervention, but that the treatment group performed significantly better than the control group in the post-test. This difference is ascribed to the PCK development of the treatment group teachers following the intervention.

The results of the study added new knowledge about transfer of generic PCK to a specific sub-topic. Furthermore, it expanded the scarce literature on the influence of PCK interventions on learners' performance. In the field of Physics Education, the study also added new knowledge about teaching EMI in Physics Education.

LANGUAGE EDITOR`S DISCLAIMER.

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DEDICATION

I dedicate this research to my:

- Wonderful mother TENDAYI MELODY MAYOWE who inspired me to aim higher in life and has always expected the best from me.
- Brother TAPIWA DZIKITI who has always loved and considered me as his perfect and personal role-model.
- Children for having always believed in my academic work.

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I whole-heartedly acknowledge with thanks the almighty God for having granted me the lifetime chance of achieving this higher calibre scholarly qualification. I shall always praise and worship him forever.

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I also want to thank Dr Corene Coetzee for allowing me to adopt her rubric which I used for PCK scoring in this study.

Professional editor Mike Leisegang for having given this manuscript a thorough language editing. Furthermore, I would like to extend my appreciation for having also done the proof-reading for me before my final submission.

Last, but not least, I give many more thanks to the Head of Education Department and all the other stakeholders in Mpumalanga province, for granting me permission to carry out my studies in their schools. Thank you for giving me the go-ahead to execute my research study. I will in due course avail the findings of this study to the Education Department.

Keywords: Pedagogical content knowledge (PCK); Refined consensus model (RCM), Electromagnetic induction (EMI), Content representation (CoRe), Curriculum assessment policy statement (CAPS), Magnetic flux (MF), Faraday`s law (FL).

LIST OF ACRONYMS

ATP	annual teaching plan
CAPS	curriculum assessment policy statement
CIE	computer-integrated education
CK	content knowledge
CM	consensus model
CoRe	content representation
cPCK	collective PCK
CS	curriculum saliency
CTS	conceptual teaching strategy
EMF	electromotive force
EMI	electromagnetic induction
ePCK	enacted PCK
FL	Faraday’s law
GR	grand rubric
GTPCK	general taxonomy of PCK
ICT	information and communications technology
MF	magnetic flux
MSTA	Mathematics, Science, and Technology academy
PCK	Pedagogical content knowledge
PhET	Physics Education Technology
PK	Pedagogical knowledge
pPCK	personal PCK
RCM	refined consensus model
RHR	right-hand rule
rPCK	reported PCK
SCK	specific content knowledge
SI	International System of Units. SI stands for *Système International*
SME	subject matter expert
SMK	subject matter knowledge
SMCK	subject matter content knowledge
SSI	semi-structured interview
TPCKA	taxonomy of PCK attributes
TSPCK	topic-specific professional knowledge
VPB	video play back
VSRI	Video-stimulated recall interview

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Many Science teachers are experiencing a lot of challenges. One of the primary challenges involves adapting their subject matter knowledge and making it possible for their learners to understand it. This can lead to pressure being mounted on Science teachers being expected to produce learners with good results needed to enter the Fourth Industrial Revolution with confidence. However, such expectations cannot be fulfilled if no support or intervention related to teachers' pedagogical content knowledge is instituted. Hence, there is a need to investigate the effect of a PCK intervention on teachers' PCK and ultimate learner performance.

1.2 BACKGROUND

The kind of experience related to the development of professional knowledge in in-service teachers cannot be easily captured due to its personal and tacit nature (Coetzee et al., 2020). Although there might be some common content delivery approaches amongst expert teachers (Krepf et al., 2017), individual teachers retain some unique kind of professional knowledge of practice (Kind, 2009). It is such kind of knowledge that separates teachers from every other profession (Jacob et al., 2020). Shulman (1986) called this professional knowledge which characterises practising teachers pedagogical content knowledge (PCK). PCK is the unique knowledge teachers have that enables them to make content understandable to learners. This knowledge distinguishes a teacher from a person who is only a subject specialist and not a teacher. The teaching profession has, as part of its mandate, the duty to disseminate knowledge which enables learners to develop skills of mastering concepts within a specific topic (Mavhunga, 2018), hence the expected level of teachers' content knowledge (CK) is consensually high (Coetzee, 2018). However, for one to be deemed a good teacher, CK on its own cannot suffice without PCK and pedagogical reasoning needed during lesson execution (Mavhunga et al., 2016). In other words, a teacher with only CK remains professionally incomplete until they can skilfully administer PCK while presenting CK to learners (Buma & Sibanda, 2022).

Most researchers agree on the need for continued professional teacher development (Kirschner et al., 2015), hence the proposed PCK model by Shulman (1986) has received widespread support from many educationists (Kagan, 1990; Alonzo & Kim, 2016; Mazibe et al., 2018; Carlson et al., 2019; Liepertz & Borowski, 2019). PCK is considered by Kind (2009) as a highly influential kind of teacher's professional knowledge, which if harnessed properly can result in effective teaching and learning (Loughran et al., 2012). The past decade has seen PCK researchers predicating on the developmental efforts of generating teacher specific knowledge (Mavhunga, 2018). This involved the process of capturing and evaluation of PCK development amongst in-service teachers (Buma & Sibanda, 2022). PCK education experts have proposed that teachers with PCK of higher quality are exceptionally competent during teaching (Kirschner et al., 2015), hence the uniqueness of how teachers interact with learners during lesson deliverance in the specific context under which the lesson is delivered is attributed to teacher's PCK (Mavhunga, 2018) When it comes to Science education, the global community has fully acknowledged PCK as a leading construct required for comprehending the knowledge of the Science teacher (Mazibe et al., 2018), and the role it plays in supporting the process of effective teaching and learning (Park & Suh, 2015).

1.3 THE PROBLEM STATEMENT

The quality of teaching has been identified as one of the important factors needed for the generation of productive future citizens of a growing economy such as South Africa (SA) (Mavhunga & Rollnick, 2013).

Millar et al. (2018) argue that if Science and society was integrated in Science teaching this would lead to learners becoming scientifically literate. That will empower them to be well-informed in the decision-making process collectively and individually.

Even though most nations the world over are now primarily concerned about the level of learners' achievement (Aydeniz & Gurcay, 2018). PCK researchers encourage learning beyond examinations alone (Liepertz & Borowski, 2019). Various education departments from different governments throughout the world are in need of professional advice from those in research frontiers (Coetzee, 2018), probably on how best to create the right environment with an adequate supply of PCK-competent in-service teachers who prioritise conceptual understanding of Physical Sciences.

Contemporary PCK researchers have dwelt much on pre-service teachers. Most of their findings suggest that pre-service teachers' PCK is a valuable construct to map and analyse conceptual teaching in Physical Sciences. The following topics have so far attracted research attention from PCK scholars: quantitative chemistry (Hume & Berry, 2010), chemical equilibrium (Mavhunga, 2018), graphs in motion (Mazibe et al., 2018), particulate nature of matter (Buma & Sibanda, 2022), mathematics lesson planning analysis (Moh'd et al., 2022), electric circuits (Akinyemi, 2016) geometrical optics (Erwin & Rustaman, 2017) heat and temperature (Aydeniz & Gurcay, 2018) and EMI (Coetzee et al., 2020). These topics are part of the curriculum assessment policy statement (CAPS) syllabus's further education and training (FET) curriculum.

Many learners have been reported to face challenges when tackling questions associated with the abstract topic of EMI (Sorge et al., 2019), primarily because of misconceptions (Hekkenberg et al., 2015) and teacher's inadequate PCK (Liepertz & Borowski, 2019). Furthermore, the issue of misconceptions associated with electricity and magnetism being intimately related was reiterated by Mavhunga et al. (2016) in their studies based on PCK for electric circuits.

Studies based on in-service teachers' PCK have been very few and extensive research is yet be conducted, (Sorge et al., 2019). Jelicic et al. (2017) suggested the need for teachers to further develop their pedagogical approaches to explain the concept of EMI to learners. Coetzee (2018) reported the existence of a significant gap between the reported PCK and enacted PCK amongst pre-service teachers in the Grade 11 topic of EMI. The issue of transfer of PCK from one topic to another has not been well researched, apart from what Mavunga and Rollnick conducted in Chemistry (Mavhunga & Rollnick, 2016). Although some studies have been conducted by PCK researchers to try and establish the level of agreement between in-service teachers' reported and enacted PCK (Krepf et al., 2017), its ultimate contribution to the performance of Grade 11 learners in the topic of EMI has not been explored. Despite the proposed numerous advantages of PCK especially for pre-service teachers in improving learners' conceptual understanding and performance (Mazibe et al., 2018), more studies are yet to be carried out to explore the link between in-service teachers' PCK and learner outcomes and the effectiveness of PCK transfer in enhancing learner performance (Buma & Sibanda, 2022).

1.4 RATIONALE

Regardless of the significance of PCK to the teaching fraternity, the teachers' lesson preparation approaches have been noted to inadequately deal with the implications on learners' conceptualisation of specific topics of science (Buma & Sibanda, 2022). Some Physics teachers have been reported by Halim and Meerah (2002) to exhibit PCK deficiency through their inadequate CK, consequently affecting their judgement of learner-held alternative conceptions. Additionally, Van Driel et al., (2002) reported the existence of CK gaps amongst novice and pre-service Chemistry teachers. Professional skills related to the composition of subject matter knowledge have been acknowledged as essential for effective teaching by Ball et al., (2008). The abstract pedagogical concepts and ideas associated with teaching makes it difficult, hence, some teachers have been observed to avoid approaches which promote conceptual understanding and resort to simplified methods which amount to meaningless rote learning (Buma & Sibanda, 2022, Loughran et al., 2012).

Bertram (2010) reported that Science teachers might add value to and influence their professional knowledge through adopting content representations (CoRes) in their lesson preparation and during classroom practice.

Mavhunga (2018) noted that teachers were not excluded from having some topic-specific misconceptions. This concurs with the findings from a study by (Hekkenberg, 2012) and (Sorge et al., 2019), suggesting the need for more research to be conducted in Physical Sciences.

EMI is one of the content topics prescribed in SA’s Grade 11 CAPS syllabus and, most Grade 11 learners find it difficult (Sağlam & Millar, 2006), even after being taught by some experienced teachers. The differentiated instructional strategies to be employed for an effective lesson execution based on Grade 11 EMI demand teachers to have well-developed PCK. Furthermore, the demand in experimental work needed for learners to fully understand EMI requires the presence of a competent teacher (Buma & Sibanda, 2022). If in-service teachers are adequately armed with sound PCK, it becomes possible to teach topics that are considered difficult (Krepf et al., 2017); hence, the teachers should manage to assist learners in creating cognitive links between the theory and reality (Grossman, 1990), in a difficult topic like EMI.

An intervention for every challenging topic is not feasible as it is time consuming and expensive. The main aim of the study is in fact to investigate possible effects of a generic PCK intervention. In other words, the researcher is interested in investigating the teacher’s pedagogical content knowledge and learners’ performance in electromagnetic induction following a generic intervention.

1.5 PURPOSE OF THE STUDY

This study aims to investigate if a generic PCK intervention can ultimately result in enhanced PCK and learner performance in a specific topic.

1.6 RESEARCH QUESTIONS

The principal research question which guided this study was:

What is the effect of a generic PCK-based intervention on in-service teachers’ PCK and their learners’ performance in EMI, and how can it be understood?

In order to respond to the main research question, the following sub-questions were formulated:

I. What is the influence of the intervention on the teachers’ personal PCK?

II. To what extent is the teachers' personal PCK manifested in the enacted PCK?

III. What is the influence of the teachers' enacted PCK on the performance of their learners?

1.7 WORKING ASSUMPTIONS

The working assumptions for this study have been formulated as follows:

I. Teachers' PCK can be captured and evaluated in terms of components.
II. Learners conceptual understanding of EM can be measured by test scores.
III. The in-service teachers conduct lesson preparations before teaching Physical Sciences topics such as Grade 11 EMI.
IV. The data gathering research instruments used in this study can effectively assist in capturing the teachers' PCK.

1.8 SUMMARY OF CHAPTER 1

In this chapter, the researcher started by introducing the study and then discussed the background of PCK. The researcher went on to provide the problem statement which identified the knowledge gap and consequently led to the recognition of the need for such a study to be conducted. What followed was the rationale and the principal purpose that triggered the study and upon which the research was solely based. The main research question and the associated research sub-questions were formulated to pave the way for a comprehensive study to be conducted. The chapter was concluded by the formulation of the working assumptions underpinning the research study.

1.9 REPORTING ABOUT THE STUDY IN THIS THESIS.

In this thesis, the researcher reports in six chapters on the study based on the effect of a generic PCK intervention on teachers' PCK and learners' performance in electromagnetic induction. What follows is a brief outline of each chapter:

In the discussion in Chapter 1, the researcher starts by providing the background of the entire research study. The researcher then focuses on the problem statement which identifies the knowledge gap and consequently triggering the need for a study to be conducted. What follows is the rationale and the principal purpose of the study and upon which the research was based. The summary of research questions formulated to pave the way for a comprehensive study to be conducted is then be discussed. The chapter is concluded by presenting the formulated working assumptions upon which the research study was based.

In Chapter 2, discussions are based on the literature review which guided the direction of this study. The literature review starts by focusing on PCK as a construct. The discussion based on PCK considers ‘the taxonomy of PCK, the development of PCK through research and developing PCK in a teacher’s mind. The recently formulated refined consensus model (RCM) of PCK is discussed in this chapter as the basis for the conceptual framework of this study. The use of the CoRe tool for capturing teachers’ PCK as well the rubric used for assessing teachers’ PCK is discussed in this chapter. The researcher concludes the chapter by discussing literature related to electromagnetism in the South African curriculum and methods and challenges associated with teaching electromagnetism.

Chapter 3 gives a full description of the ontological and epistemological implications of the research methodology implemented in the study. The mixed methods research (qualitative and quantitative) approach and data analysis approach is discussed in this chapter. The intervention approach upon which the first sub-question is based is discussed in this chapter. The researcher discusses the research design and sampling methods, multiple data collection methods, validity, and reliability of research findings. The chapter is concluded by a discussion based on ethical considerations.

Chapter 4 presents qualitative data collected from treatment group teachers during this study. This chapter discusses in detail the individual teachers’ responses to pre-CoRe, post-CoRe and how the scoring of the responses using a rubric adapted from Coetzee (2018). The discussion involves comparison of pre- and post- scores.

The narrative view of how teachers enacted their PCK through the use of video-recorded lessons, how they responded to video-stimulated recall (VSR) interview sessions and semi-structured interview sessions are discussed in this chapter. The qualitative analysis and discussion involve how the teachers enacted PCK is scored and compared with post-CoRe scores. The researcher concludes the chapter by conducting in-depth analysis of the qualitative findings.

Chapter 5 presents analysis of the quantitative results obtained from learner participants of the eight schools. The baseline test results were quantitatively analysed to see whether the control group and the experimental group were at the same level before PCK intervention was instituted. The control group and experimental group were compared at the end of the intervention by means of a post-test. The results of the post-test were quantitatively analysed to see if the PCK intervention had an impact on learner performance. The quantitative analysis and discussion of the post-test results assisted in responding to the third research sub-question.

Chapter 6 presents the concluding remarks of this study. The researcher summarises the findings from both qualitative and quantitative research outcomes in response to main and sub-questions. The implications, limitations and recommendations for future researchers are discussed in this chapter. The researcher then concludes by presenting his views based on personal experiences attained during the study.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter the researcher began by focusing on literature related to PCK as a construct and the taxonomy of PCK. The researcher then discussed the research developments of PCK in general followed by the refined consensus model of the PCK. This was followed by the conceptual framework that guided the study. The researcher then discussed the research developments of PCK in general. This was followed by the literature reflecting the various methods and approaches of how other researchers have been capturing teachers' PCK. The construction of CoRes and use of the rubrics to assess teachers' personal and enacted PCK was discussed in line with literature. The researcher paid attention to EMI as a curriculum topic in Grade 11.

2.2 PCK AS A CONSTRUCT

Shulman (1986) proposed the PCK construct as specialised teacher knowledge to make content understandable to learners. He described PCK as the specific type of knowledge which embraces the aspects of content most crucial to its teaching. Furthermore, he emphasised that PCK involves formulating ways of representing subject-specific content using means that can be easily understood by others. Additionally, Shulman (1987) suggested the comprehension of specific content as one of the teachers' additional PCK attributes. Shulman (1987) pointed out that PCK involves the teacher's translation of content knowledge into forms adapted to an individual learner's learning difficulties and variable prior knowledge. This means that the development of PCK generated knowledge and included concepts based on the content and learners' everyday experiences.

Grossman (1990) further elaborated on PCK as a pedagogical construct generated as a result of a teacher's knowledge of specific topics and its representation during teaching and learning. In other words, PCK equips teachers to be capable of developing skills to select suitable curriculum content. Geddis (1993) considered PCK as an array with attributes which assisted a teacher in transferring content knowledge to learners. This was further echoed by Miheso and Mavhunga (2020), elaborating on PCK as a construct needed by Physical Sciences teachers to assist in confronting learners' misconceptions that affect learning process.

According to Berry et al. (2008), PCK is regarded as one of the knowledge bases used by teachers to represent academic content in a contextual way. According to Abell (2008), PCK is that kind of teachers' special skill used during teaching which makes knowledge readily accessible to students of any calibre. Furthermore, Abell (2008) highlighted Shulman's advocacy for a PCK, which included the total comprehension, full organisation, and proper presentation of topic-specific problems to cater for the diverse interests of learners of various abilities.

Depaepe et al. (2013) referred to PCK as a professional knowledge uniquely possessed by teachers to assist students in understanding what they know, what they need to know, and how best they ought to maximise their potential. Some researchers view PCK as an outcome of a teacher’s transformed subject matter content knowledge (SMCK) (Henze & Van Driel, 2015), hence the teacher’s quality of knowledge embedded in PCK ought to remain vital to ensure effective learning and teaching (Jing-Jing, 2014). Kind (2009) regarded PCK as an intrinsic skill of teaching knowledge to somebody who does not know it. The same point was echoed by Coetzee et al. (2020), who pointed to the fact that PCK enables teachers to present ideas of the scientific discipline in an understandable way to non-experts. It is therefore imperative to regard PCK as a construct involving knowledge transformation, which makes it easy for learners to understand.

The conceptualisation of PCK has been embraced in Science education where a considerable amount of research is underway globally (Mavhunga, 2014). According to Mazibe et al. (2018), PCK is considered as that knowledge necessary for Science education to progress. This concurs with Park (2005), who regards PCK as a higher-order professional knowledge and form of specialisation articulated especially by Science teachers. The PCK knowledge entails organising, representing, and solving problems of specific Science topics for effective teaching (Krepf et al., 2017). Krepf et al. (2017) noted poor subject matter knowledge amongst Science teachers as a major drawback in their PCK.

2.3 THE TAXONOMY OF PCK

Grossman (1990) proposed the PCK framework while emphasizing on the integration of pedagogical and content knowledge for effective teaching. Geddis extended this by introducing PCK categories which involve transforming subject matter knowledge into pedagogically powerful representations for teaching (Geddis,1993). In other words, the proposals by Grossman and Geddis, all contributed to understanding the complex interplay between content and pedagogy in teacher knowledge.

Veal and MaKinster`s PCK taxonomy was built upon Shulman`s PCK framework. The identification and classification of different types of PCK into various epistemological categories is important for prospective PCK researchers (Veal & MaKinster, 1999). While Geddis identified general PCK categories, Veal and MaKinster refined and expanded them, proposing a taxonomy with specific dimensions (Shing et al., 2015). According to Veal and MaKinster (1999), there are two major PCK taxonomies, the general taxonomy of PCK

(GTPCK) and the taxonomy of PCK attributes (TPCKA). The GTPCK focuses on classification of PCK in terms of grain size namely: *subject-specific PCK*, *domain-specific PCK* and *topic-specific PCK*. The TPCKA is aimed at generating a full list of epistemological components needed for PCK development.

The TPCKA entails three levels namely: content knowledge in PCK development; knowledge of students and experience-related attributes. *Content knowledge i*n PCK development is the most important attribute. A teacher's *knowledge of students* is the second-most important attribute of the TPCKA. This entails a thorough comprehension of student errors and alternative conceptions. In other words, it is only through a teacher's thorough understanding and skill to interconnect their content knowledge with their knowledge of their students. PCK is the third attribute, consisting of eight other inter-related PCK attributes: assessment; context; socio-culturalism; classroom management; pedagogy; curriculum; environment and nature of science. These are not necessarily arranged hierarchically but can only be developed through teaching experience. Essentially Veal and MaKinster`s taxonomy offers a more detailed breakdown of the components within Shulman`s PCK, providing a nuanced view of the teacher`s knowledge base.

2.4 DEVELOPMENT OF PCK THROUGH RESEARCH

Ever since its introduction, PCK as construct has been refined (Berry et al., 2008) and developed theoretically to describe its characteristics (Jing-Jing, 2014). Some of the changes include the way we understand knowledge categories present and how they relate to each other. As discussed by Kind (2009), developments in PCK research chose to retain Shulman's original reasoning regarding subject matter knowledge (SMK) but provided additional components. A similar observation was made by Jing-Jing (2014) who noted a considerable number of clarifications related to new and adjusted components especially the sub-components by Gudmundsdottir and Shulman (1987). The additional component related to knowledge of evaluation was introduced by Tamir (1988) while Grossman (1990) added 'purposeful teaching'. Magnusson et al. (1999) suggested teaching orientation to Science pedagogy to be of great value for moulding the other components of knowledge.

The propositions set out by Polanyi (1958) and later paraphrased by Hegarty (2000, p. 453), suggested the subjectivity, context specificity and incommunicability of tacit knowledge except through demonstrating it in practice. Researchers are endeavouring to redefine knowledge related to the components of PCK and how they interact with the transformation of specific science topics (Mavhunga, 2018). Various methods related to PCK studies have been observed over six decades all pointing towards the implicitness or tacit nature of PCK knowledge (McNeill et al., 2016). Shulman (1986) argued that the vital ingredients of teachers' knowledge are: a) subject matter content knowledge, b) pedagogical content knowledge and c) knowledge of the curriculum. Shulman (1987) further proposed that PCK included representational formulations of Science ideas, the very strong analogies, good illustrations, relevant subject-related examples, powerful explanations, and appropriate demonstrations resulting in easier comprehension. Additionally, Baxter and Lederman, (1999); Park, (2005) and Magnusson et al. (1999) reiterated that Science teachers' PCK should consist of five components: orientations towards Science teaching, knowledge of curricular saliency, assessment knowledge, knowledge of learners' comprehension of Science, and knowledge related to conceptual teaching strategies. Furthermore, the amalgamation of content and pedagogy should be adapted to carter for learners of different intellectual backgrounds (Berry et al., 2008). Gudmundsdottir and Shulman (1987) regard great teachers as those whose PCK results from merging content of subject and pedagogical skills, hence, for teachers to realise their full potential, this calls for them to develop specific instructional strategies and modernised representation methods that would aid learning process (Veal & MaKinster,1999).

Mavhunga and Rollnick (2013)'s studies based specifically on pre-service science teachers' professional development focused on five TSPCK components. The five TSPCK transforming knowledge components are: Learner prior knowledge; Curricular saliency; What is difficult to teach; Representations including analogies; and Conceptual teaching strategies. Besides the distinctive features to be noted by Hill et al. (2008) between SMK, and specific content knowledge (SCK), Mavhunga et al. (2016) additionally emphasised knowledge of curriculum and pedagogical knowledge as key PCK elements. Furthermore, Depaepe et al. (2013) noted that knowledge related to ends, values, purpose, philosophy, and context of education are all informed by PCK. The distinction between transformative and integrative models were also advocated for by Gess-Newsome (2015). The observations by Krepf et al. (2017) and Buma and Sibanda (2022) seem to hold some relevance to this study as they place more emphasis and interest in analysing in-service teachers' practical experiences as well as the potential to provide feasible research methods. However, emphasis on how the teacher's practical experiences will impact on learner performance has so far been demonstrated by few researchers (Alonzo & Kim 2016; Mazibe et al., 2018).

Henze and Van Driel (2015) indicated that the implicit stature of PCK involves the translation of content knowledge (CK) also called subject matter knowledge (SMK). This according to Jacob et al. (2020) eventually becomes any kind of student's ultimate knowledge base. PCK-based research has been tailored towards making it the teacher's intrinsic knowledge base (Mazibe et al., 2018), hence if teachers were to be accorded the latitude of explicitly externalising their tacit knowledge, then it might bear some limitations of being passed on immediately (Mavhunga et al., 2016).

According to Mavhunga et al. (2016), beliefs and knowledge about the subject and the learners can never be ruled out when giving instructions based on PCK research methods. This notion was earlier mentioned by Turner-Bisset (2013) who argued that a learner's experiences were directly influenced by their teachers' beliefs related to a specific subject or content. That is why some researchers advocate for evidence-based teaching to probe the presentation methods and unveil the beliefs and knowledge that underpins the teacher's pedagogical approach (Gudmundsdottir & Shulman, 1987; Kind, 2009; Mavhunga, 2014; Mazibe et al., 2018). Buma and Sibanda (2022) noted the importance of understanding PCK in order to include teachers' beliefs and deduce methods which have been implemented by other scholars for PCK development. Furthermore, the research methods agenda related to professional capacity construction had to support the (tacit) beliefs, knowledge and craft involved (Coetzee, 2018). Mavhunga et al. (2016) further reiterated that PCK is a vital construct of knowledge identified to be of great assistance to pre-service Physical Sciences teachers. This implies that PCK is at the centre stage of both pre-service and in-service teachers' knowledge. Therefore, PCK development should be tailored towards professionally moulding not only pre-service teachers but also in-service teachers.

Widodo (2017) proposed that even though PCK was yet to be classified as a skill needed by practicing teachers, poor PCK was likely to result in ineffective execution of teaching and learning activities, hence there was a need to explore the link between one's demonstration of pedagogical skills when teaching a specific topic and the expected thinking skills to be achieved by learners. Krepf et al. (2017) observed noticeable differences in the knowledge of PCK components of novice and expert teachers through the use of video-recorded Chemistry lessons. In their report they remarked that expert teachers demonstrated a knowledge of integration and interrelatedness of PCK using methods which corelated with effective teaching. Buma and Sibanda (2022) conducted a study based on pre-service and in-service teachers' enacted PCK focusing on particulate nature of matter. Their research findings revealed that pre-service teachers demonstrated a better ability to integrate components of enacted PCK (ePCK) if compared to in-service teachers. However, no mention was made regarding PCK impact on learner's performance. Research carried out by Coetzee et al., (2020) revealed the lack of opportunities by pre-service teachers of integrating their CK with their pedagogical skills, thus leading to PCK of mediocre quality. However, no mention or emphasis was made on how the teachers' PCK development would impact on learner performance. This suggests the importance of experience as a necessary but not sufficient component for teachers' PCK development.

Mazibe et al. (2018) conducted a comparative study of reported and enacted PCK amongst pre-service teachers. Their research findings suggested that the teachers' declarative PCK and enacted PCK in the Grade 10 Physical Sciences topic of graphs of motion were not always in agreement.

2.5 DEVELOPING PCK IN A TEACHER'S MIND

Some earlier researchers (Veal & MaKinster, 1999; Ball et al., 2008) accepted PCK as a construct uniquely developed in specific subjects and topics. This concurs with some of the contemporary PCK researchers (Coetzee et al., 2020; Krepf et al., 2017; Mavhunga et al., 2016; Buma & Sibanda, 2022) who considered PCK as valuable to investigate the teaching of specific topics (Mazibe et al., 2018). On the other hand, the constructivist stance reflected in the dynamic version of PCK, places more emphasis on an action-based kind of knowledge (Seymour & Lehrer, 2006). In other words, it is the kind of PCK advocated for by Shulman (1987) as it bears reflective and stimulative characteristics. Contemporary PCK researchers have paid more attention to PCK from an empirical perspective and its intellectual effects (Coetzee, 2018; Krepf et al., 2017, Buma & Sibanda, 2022; Iserbyt et al., 2017), with better comprehensive interventions being taken into consideration (McNeill et al., 2016) to develop PCK, hence the uniqueness of PCK as a knowledge base for professional teachers should be accommodated in every formal pedagogical set-up and curriculum of all subjects.

Studies have proved that a teacher's classroom experience plays a vital role in PCK development (Mavhunga, 2018; Buma & Sibanda 2022; Krepf et al., 2017). Lesson planning, preparation, presentation, assessment, and reflecting is part of such needed experience (Krepf et al., 2017). Experienced and novice teachers have been reported to be at different levels of PCK development. with experienced teachers exhibiting greater knowledge of PCK components (Buma & Sibanda 2022), and expert ability of interconnecting the relationship between components than novice ones (Abell, 2008). It has been reported amongst in-service teachers that the fragmentation of their PCK can be a result of teaching without consciously demonstrating pedagogical reasoning (Krepf et al., 2017). As such, their learners are less likely to experience effective learning (McNeill et al., 2016).

Exactly how the development of PCK occurs amongst teachers is part of the ongoing debates in educational research (Coetzee et al., 2020; Moh'd et al., 2022; Jacob et al., 2020) with some arguing that there is no prescribed way in which PCK development can be described (Mavhunga et al., 2016). Hashweh (2005) argues that the ability of a teacher to take the initiative in constructing unique approaches when teaching a difficult or new concept to learners is indicative of their PCK development. From another angle, this involves the teacher’s use of PCK components especially when confronted with new content (Große-Heilmann et al., 2022). This implies that a teacher who interacts or uses more components during a period of PCK enactment is deemed to be more competent (Miheso & Mavhunga, 2020).

Mavhunga (2014) advocates for engagement in microteaching to develop PCK. Große-Heilmann et al. (2022) argue that continued teacher professional development interventions provide a good breeding ground for PCK development. An investigation by Jacob et al. (2020), based on some in-service teachers’ knowledge of non-familiar topics showed that they could transfer expert knowledge, hence, inadequate knowledge on subject matter hampered the development of their PCK development (Mavhunga, 2018). Rollnick et al. (2015)’s observations based on in-service teachers showed that they gained new knowledge related to subject matter, thus resulting in their PCK developing.

2.6 INFLUENCE OF TEACHER`S PCK ON LEARNER PERFORMANCE

PCK is crucial for learner performance as it involves teachers` understanding of how to convey specific content in a way that facilitates students` learning (Alonzo & Kim, 2016). A teacher with strong and solid PCK comprehends not only the subject matter but also shows how to present it effectively (Mazibe et al., 2023), addressing learners` needs and challenges (Alonzo & Kim, 2016). For instance, in the topic of electromagnetic induction, a teacher with strong PCK should be able to breakdown complex concepts into understandable parts (Coetzee, 2018), and provide clear and accessible explanations to the learners (Hekkenberg et al., 2015). Furthermore, teachers can design engaging lessons, provide meaningful and relevant examples, and employ diverse teaching strategies to carter for the students` learning styles (Alonzo & Kim, 2016). This knowledge enables education to tailor their teaching methods, materials, and assessments (Keller et al., 2017) to enhance comprehension and engagement, ultimately positively impacting learner performance (Alonzo et al., 2012). Besides enhancing students` understanding and overall performance, it also enhances motivation (Alonzo & Kim, 2016). Conversely, insufficient PCK may lead to challenges in conveying information (Mazibe et al., 2023), potentially hindering the learners` comprehension and academic achievements (Gess-Newsome et al., 2019). A study conducted by Alonzo et al. (2012) based on exploring whether a relationship existed between teachers’ PCK and their learner performance revealed evidence of a positive relationship. Gess-Newsome et al. (2019) reported lack of a relationship while Mazibe et al. (2023) observed a correlation between PCK and learner performance. It was part of the current study to also explore the impact of teachers` PCK on learner performance.

2.7 REFINED CONSENSUS MODEL

The 2012 PCK summit proposed a universal model of skill and knowledge of professional Science teaching. The model was later considered as the consensus model (CM) (Gess-Newsome, 2015). The CM suggested a necessary framework for the inter-dependent relationships amongst Science teachers' different professional knowledge bases. The CM advocates proposed that the comprehension of the PCK construct should focus mainly on PCK within a topic and called it topic-specific professional knowledge (TSPK) (Gess-Newsome & Carlson, 2013). The TSPK construct is similar to what Mavhunga and Rollnick (2013) conceptualised as topic-specific PCK (TSPCK). In a related study based on the Pentagon PCK model, Aydin and Boz (2013) observed that the integration of PCK components was more coherent amongst the in-service teachers, hence, knowledge based on learner misconceptions and conceptual teaching strategy were at the core of integration of components (Mavhunga, 2014).

The CM allows the focus to be directed towards methods of appreciating CK for teaching purposes (Henze & Van Driel, 2015). Similarly, Mavhunga (2014) reiterated that the CM puts more emphasis on CK and that it should therefore be topic-specific and not subject-specific. This creates room for Science teachers to filter the content and place more emphasis on knowledge regarded as important (Gess-Newsome, 2015).

Gess-Newsome (2015) portrayed five PCK components modelled in pentagonal style. The components included in the pentagon model were: knowledge of learner understanding of science, knowledge related to science's curricular saliency, knowledge related to instructional strategies, science teaching representations, and knowledge related to science assessments.

Efforts focusing on the different ways of using the PCK construct has led to a recent movement towards explicit definitions of PCK related constructs (Carlson et al., 2019). This resulted in the refined consensus model (RCM) of PCK. The RCM features the PCK in three different realms namely, collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK). In other words, the distinction between the three different realms of PCK is a prominent characteristic of the RCM. The educational context can assist in mediating the dynamic movement of knowledge amongst the three PCK realms. Furthermore, it is possible to analyse the different realms of PCK at various grain sizes of discipline, topic and concept in alignment with the ideas of Veal and MaKinster (1999).

The realm of cPCK represents subject matter experts (SMEs)'s collective views about teaching subject specific topics and topic specific concepts (Carlson et al., 2019). This is not about subject content knowledge: it is the collective knowledge held by the profession about the teaching of the content. On the other hand, pPCK is a field of specialised knowledge of the teacher which develops through experiences in classroom practice (Carlson et al., 2019). The pPCK of in-service Physical Sciences teachers is tacit, hidden, highly personal, deeply contextualised and greatly driven by professional experiences and interactions derived from cPCK (Van Dijk & Kattmann, 2007). The teacher's knowledge and skills related to PCK complement each other with learning outcomes (Carlson et al., 2019). The realm of pPCK is often measured outside the classroom before lesson delivery (Henze & Van Driel, 2015). The realm of ePCK, is practical manifestation of pPCK observed when a teacher plans, teaches, and later on reflects on the lesson, (Carlson et al., 2019). The realm of ePCK depicts the knowledge and teaching approaches which a teacher demonstrates in class (Kagan, 1990). This means that ePCK can be captured during lesson delivery (Henze & Van Driel, 2015). The teacher's enacted PCK is essential in the teacher's capacity skills development as well as consolidating learners' performance-based outcome (Chan et al., 2019). Furthermore, learners' performance is a crucial indicator required to continuously develop and aid in reconstruction of an in-service teacher's personal and enacted PCK and, essential experiences needed for PCK development (Mazibe et al., 2018).

The realms of pPCK and ePCK were earlier described by other researchers, using different terminology. Alonzo and Kim (2016) used the terms static and dynamic PCK respectively. On the other hand, reported PCK (rPCK) refers to teachers' knowledge and ideas about teaching the topic, communicated in interviews, questionnaires or lesson plans prior to lesson execution (Mazibe et al., 2018). Reported PCK is not in the RCM framework. It is a label that is used by researchers to indicate the way they accessed or captured the pPCK. So rPCK is actually pPCK captured through interviews and CoRes. A study conducted by Alonzo and Kim (2016), has suggested the importance of linking rPCK with ePCK to effect ultimate learner performance. More details about the interrelatedness between cPCK, pPCK and ePCK are provided as theoretical framework.

2.8 CONCEPTUAL FRAMEWORK

The conceptual framework developed for this study was adapted from the refined consensus model (RCM) (Carlson et al., 2019). The knowledge and skills learnt during the intervention enriches teachers` enacted PCK and their professional knowledge base. The ePCK manifesting during classroom practice is influenced by the teacher's enriched pPCK. The enriched pPCK together with ePCK builds up into the teacher's personal PCK.

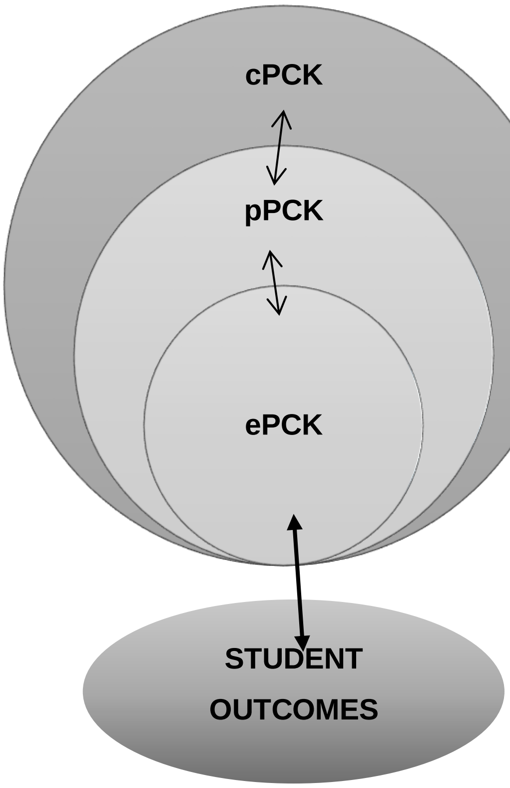


Figure 2.1: The conceptual framework adapted from RCM. Source: Carlson et al., 2019.

The conceptual framework shown in Figure 2.1 reflects how the practical knowledge of an in-service teacher can be supported and professionally developed, to enhance learner outcomes as a visible outcome as desired by the RCM (Carlson et al., 2019). The PCK intervention applied in the current study can be viewed as the knowledge flow represented by the arrow from cPCK to pPCK, thereby developing the teacher's pPCK. The translation of such enhanced pPCK into action is represented by the arrow from pPCK to ePCK. This arrow indicates the influence of the intervention on learner outcomes, while the feedback arrow into pPCK represents further knowledge about the successes and failures of new approaches. The ePCK can be measured in learner outcomes and explained in terms of the changes in the teacher's pPCK utilised in ePCK, hence the adoption of the conceptual framework outlined in this section shall be assistive in realising the effect of a generic PCK based intervention on the teachers' personal PCK, ePCK and learners' performance in EMI.

2.9 CAPTURING THE TEACHER'S PCK

Loughran et al. (2004) developed a tool which could be useful in the capturing and description of a teacher's PCK. This involved an attempt to capture how a teacher thinks through the use of a (CoRe) template which bears specific prompts. Firstly, the teacher provides a few big ideas on the topic. Next, the teacher is prompted to write down their ideas about teaching these big ideas. The CoRe template is by its nature used to capture qualitative data related to the teacher's PCK (Loughran et al., 2004). This means that the qualitative data captured through the use of the CoRe can provide clear insight into a teacher's understanding about teaching the topic. According to Loughran et al. (2004), it is worthwhile for a teacher to complete their CoRes prior to lesson execution. In other words, the teacher develops their CoRes in order to capture topic-specific knowledge needed during lesson delivery. This will go a long way in assisting to codify the in-service teachers' knowledge in a way that is common across the examinable content area (Juttner & Neuhaus, 2012). Furthermore, this will help Physical Sciences teachers to identify if not recognise critical content features and respond accordingly (Loughran et al., 2004). Although CoRes have been embraced as a way of concretising PCK (Loughran et al., 2006), they have also been reported as a complicated approach to exploring the knowledge of Science teachers' PCK. Hashweh (2005) agrees about the potential of CoRes in capturing and conceptualising science teachers' PCK and its resultant development. To portray Science teachers' PCK, CoRes were used to explore their impact on in-service Science teachers' professional knowledge base (Loughran et al., 2012).

Rollnick et al. (2015) observed the impact of Science content knowledge on two RSA in-service teachers' and proved the usefulness of CoRes in the construction and development of Science teachers' PCK. Additionally, CoRes permitted the salient attributes of the teachers' PCK to be visibly exposed (Mavhunga & Rollnick, 2016).

In a study based on the nature of science conducted by Ratcliffe (2008) in the United Kingdom, the possibility of CoRes in assisting teachers to articulate their PCK was observed. CoRes were also used successfully for PCK data collection and representation on in-service teachers in Latin-America based on the science topic of 'the particulate nature of matter' (Garritz et al., 2005).

Loughran et al. (2006) investigated the effectiveness of CoRes on secondary trainee Science teachers and examined that it had an impact of shaping their thinking and PCK development as prospective Science teachers. Nilsson (2010) pointed out that CoRes presented a reasonable way of appreciating PCK as teachers' knowledge for professional practice. Abell (2008) narrated the effectiveness of lesson preparation based on CoRes in mentorship of PCK construct to prospective teachers. The interrelatedness between CoRes and lesson preparation was conducted by Maryati and Susilowati (2015) in Indonesia. Their findings revealed that lesson preparation conducted in conjunction with well-developed CoRes was realistic as teachers inevitably considered learners' conditions at planning stage. Maryati and Susilowati (2015) noted the potential of CoRes in accelerating prospective teachers' PCK development and hence realise the essence of being deemed Science teachers.

2.10 ASSESSMENT OF PCK

The knowledge demonstrated by a teacher and the way they reason at planning stage does not usually turn out to be the same way they will enact the PCK during classroom practice (Mavhunga et al., 2016). Teacher's knowledge in fixed form defines their static PCK while the knowledge which they develop in situ defines the dynamic aspect of their PCK (Vollebregt, 2020). Hence, the assessment of their personal PCK and enacted PCK will assist to seal the gap (Henze & Van Driel, 2015).

The purpose of a rubric is to extract qualitative data. In the case of a teacher's PCK, the rubric is intentionally used to qualitatively extract data needed to analyse their level of PCK development (Chan et al., 2019). Many contemporary researchers advocate for the use of the rubric system to measure a teacher's PCK against normative standards that are prescribed by research experts (Vollebregt, 2020). PCK has been observed to exist in a continuous intellectual spectrum from weak to exemplary and hence the need for a rubric (Coetzee, 2018). Rubric can purposefully be used to qualitatively investigate the teachers' knowledge and thoughts prior to their engagement with learners (Chan & Hume, 2019). Furthermore, Coetzee (2018) suggested that using a rubric to investigate the teacher's knowledge in action through what they actually do, the skills, techniques and strategies which they employ in the classroom can provide qualitative data of their dynamic PCK. Every rubric has characteristics with implications for commitment to a specific model (Mavhunga et al., 2016). About 20 rubrics have been developed to measure PCK (Mavhunga, 2018). Out of the 20, most of them (13 rubrics) were specifically meant to measure static PCK while only seven targeted the dynamic PCK which is informed by the teacher's ePCK (Große-Heilmann et al., 2022). Nearly all the developed rubrics were designed around Shulman's original PCK components such as: knowledge of learner's understanding of science and knowledge related to teaching strategies (Chan et al., 2019). Other rubric characteristics were developed to target PCK components such as knowledge of curricular saliency, knowledge of representations usage and pedagogical reasoning skills (Vollebregt, 2020).

Several PCK researchers have shown growing interest in developing PCK measurement criteria since 2012 when the PCK summit was first conducted (Mavhunga, 2014). The need to design a PCK rubric with pre-determined specific performance criteria and judgement support for PCK quality has always assumed continued growth (Chan et al., 2019). The grand rubric (GR) of PCK currently adopted by several researchers to measure and capture the qualitative nature of PCK of a Science teacher was developed by a sub-group of participants of the 2016 second PCK summit (Chan et al., 2019). The need to design the GR was perpetuated by the need for a valid, ubiquitous, unambiguous communication between researchers. The GR could be applied to different content topics of Science allowing PCK scores to be compared across topics. Furthermore, the generic nature of the GR can be useful for data triangulation across various sources to supply more evidence needed for pre- and post-intervention PCK growth.

Furthermore, the grand rubric can be used for scoring teachers' PCK utilises a three-point scale namely Limited, Adequate and Rich (Vollebregt, 2020). However, Mavhunga and Rollnick (2013) had noted earlier that the PCK score of some teachers for a particular CoRe prompt might exist between adequate and rich, hence, for the specific purposes of this study, the PCK rubric used by Coetzee (2018) for scoring pre-service teachers' CoRes based on Grade 11 electromagnetism was adapted (see Appendix G). This is because the later can flexibly measure the different RCM PCK variants. Additionally, the rubric caught the attention of the researcher due to its four-point scoring scale allowance for each CoRe prompt. The scoring rubric levels used by Coetzee (2018) were: *limited* (1), *adequate* (2), *developing* (3) and *exemplar*y (4). The rubric possesses all the GR characteristics in addition to *developing*.

2.11 ELECTROMAGNETISM IN THE SOUTH AFRICAN CURRICULUM

In South African CAPS curriculum, EMI is one of the Grade 11 physics topics (DoE, 2011). The topic is expected to be taught in line with the annual teaching plan (ATP) which is developed from the CAPS document. According to the 'grade plus six policy' in the South African Schools Act (South African Government, 1996), the approximate age of South African Grade 11s is 17 years (DoE, 2011). The expected time frame for EMI tuition and the recommendations for experiments to be conducted are specified in the ATP and CAPS document. It is expected of every teacher to comply with the guidelines and the ATP's topics sequence since all assessments, school-based, district-based, provincial-based and national-based are consistent with the ATP (DoE, 2011). In this study, the EMI topic was chosen to investigate the effect of generic PCK intervention on in-service teachers PCK. The selection of this topic was informed by the general impression portrayed by the teachers regarding the difficulties associated with conceptualising and later teaching it (Coetzee, 2018). Furthermore, the abstract nature of the topic (Dori & Belcher, 2005) causes it to be amongst the disliked topics in Physics by some teachers. Hekkenberg et al. (2015) observed that teachers' misunderstanding and common errors about electric and magnetic fields could be compared with those of their learners. Hence, there is need to investigate in-service teachers' PCK to uproot the challenges encountered during actual teaching and learning, content gaps, teacher's knowledge of the CAPS curriculum, the alternative conceptions and common errors exhibited by both learners and teachers. Jelicic et al. (2017), in their recent study observed that secondary school learners' responses based on EMI questions provided some confirmation about challenges related to common errors and alternative conceptions that they have. One example of learners' alternative conceptions is related to their perception about magnetic poles being charged leading to them erroneously believing that magnetic force is being exerted on charged particles Coetzee, (2018). Additionally, Maloney et al. (2001) reported on challenges related to differentiating between the magnetic flux and the flux change. Other learners had an impression of magnetic flux as a mere 'flow' of the field as noted by Zuza et al. (2014), hence, the EMI pedagogical approach requires concise background content knowledge and appropriate conceptual teaching strategies and representations.

2.12 TEACHING ELECTROMAGNETISM

Kriek and Grayson (2009) noted that misconceptions in EMI are not only prevalent amongst the learners but even amongst the teachers. This according to Jelicic et al. (2017), in most cases leads to teachers resorting to the use of undocumented if not unscientific models when explaining the concept of EMI to learners, hence the perpetual existence of misconceptions in Physical Sciences is one of the reasons why Mavhunga and Rollnick (2013) advocated for the need to develop PCK instruments. The PCK instruments can be used to elicit teachers' knowledge of learners' misconceptions or teachers' own misconceptions on EMI (Coetzee, 2018). According to Dzikiti (2019), the magnetic domain theory is amongst the ill-understood abstract concepts of magnetism. This usually leads to the alternative conception that magnetic poles are charged (Maloney et al., 2001). In another study based on misconceptions in EMI, Koudelkova and Dvorak (2014) found that learners hold the perception that induction occurs only when the loop in a generator rotates while magnets remain stationary. Coetzee et al. (2020) noted that students have insufficient time to apply their thinking skills associated with abstract concepts like field, flux, or magnetic induction which seem to appear to be associated with the formulas. More research works based in Physics education have repeatedly shown that students' level of conceptualisation of electromagnetism is idiosyncratic and depends highly on common and non-scientific terminology (Koudelkova & Dvorak, 2014). For instance, students' understanding of the terms such as flux or voltage is usually a contradiction of Physics concepts (Coetzee et al., 2020). Additionally, Jelicic et al. (2017) noted that students deal with higher order algorithmic problems based on electrostatics or even electric circuits are usually not capable of explaining magnetic induction using a scientific approach. Some are not even able to distinguish between the force of action at a distance and field models (Sağlam & Millar, 2006). However, learning challenges are not surprising as the electromagnetic concepts are regarded as difficult (Coetzee et al., 2020). EMI concepts are regarded as difficult since they consist of abstract relations (Chabay & Sherwood, 2006) The most surprising part is that the level of students' inadequate understanding remains unchanged even after they are taught (Hekkenberg, 2012), implying that learners' alternative conceptions in electromagnetism are retained even after receiving instructions. Hekkenberg et al. (2015) reported on the kinds of reasoning and misconceptions associated with EMI, and the skills associated with pedagogy as lacking. These have proved to be problematic during the learning process (Jelicic et al., 2017). Moreover, studies on the difficulties related to EMI assessments have proved that there exists some global commonality associated with the level of difficulties in the topic (Maloney et al., 2001; Planinic et al., 2006; Sağlam & Millar, 2006). SA's 2014 Physical Sciences diagnostic report points out that one of the contributing factors to the poor performance is misconceptions held by learners related to how a generator operates (DBE, 2015).

However, limited studies about the effect of PCK intervention on learners' performance in EMI at school level have been conducted (Mazibe et al., 2023). This study shall attempt to fill this gap in the literature, by investigating the impact of a PCK intervention on teachers' PCK and learners' performance in the Grade 11 Physics topic of EMI.

2.13 SUMMARY OF CHAPTER 2

The relevant literature related to this study was discussed in this chapter. The researcher began by paying attention to PCK as a construct and the taxonomy of PCK attributes. The researcher went on to discuss literature related to the development and evolvement of PCK through research. PCK and the refined consensus model were also discussed in this chapter. The researcher went on to discuss the conceptual framework based on the RCM and its relevance to this study. How PCK is captured and the assessment of PCK was then discussed. EMI was discussed as a curriculum concept in the South African context. The researcher went on to discuss the way EMI has historically been taught and the associated challenges.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This study was guided by the following research question:

What is the effect of a generic PCK-based intervention on in-service teachers' PCK and their learners' performance in EMI, and how can it be understood?

In order to answer the main research question, the following sub-questions have been formulated:

I. What is the influence of the intervention on the teachers' personal PCK?

II. To what extent is the teachers' personal PCK manifested in the enacted PCK?

III. What is the influence of the teachers' enacted PCK on the performance of their learners?

Based on the research question and sub-questions, the researcher adopted mixed methods as a research approach for this study as it is suitable to investigate the research problem. This approach which according to Noble and Heale (2019), is an important ingredient required for increasing the credibility and validity of findings of research. According to Social Sciences Research Laboratories (2018), any research method which makes use of more than one data collection approach to ensure validity and credible outcome, qualifies to be regarded as a triangulation. Hence, a mixed methods kind of triangulation which combined both quantitative and qualitative approaches was used in this study as a way of finding answers to the research question and sub-questions. My intention was that of seeking the knowledge related to how in-service teachers developed their personal and enacted PCK in EMI after a generic PCK intervention.

In this chapter, the researcher discusses the research paradigm and approach, the methodology together with the multiple approaches used to extract and analyse data. Furthermore, this chapter discusses how validity and credibility were enhanced.

3.2 RESEARCH PARADIGM.

The research problem required adopting interpretivism to explore a teacher's PCK development and positivism to explore learners' performance. Therefore, the mixed methods approach was adopted to conduct this study. Greene and Caracelli (1997) observed that the mixed methods inquiry may be approached from either a pragmatic or dialectic position. The dialectic method is based on the process of dialogue and discussion between conflicting ideologies (Betzner, 2008). However, the dialectic approach was inappropriate for this study as there were no conflicting viewpoints to be considered. Instead, the researcher followed the pragmatic pathway. According to Johnson (1997), the pragmatic method places more emphasis on practical feasibility and applications to the real-world. In this study the researcher adopted the pragmatist school of thought as it targets to find effective solutions to real world problems. Furthermore, the pragmatic method assesses contextual relevance of ideas in real life. Hence, the pragmatic approach was adopted in this study due to its appropriateness in addressing the research question and sub-questions. The pragmatic stance appeals and responds contextually to the opportunities and even constraints of a situation (Rossman & Wilson, 1985). In other words, the pragmatic stance responded to the situation of my research problem.

From the interpretivist view, there is no single reality or truth (Guba & Lincoln, 1994), reality is created by individuals in groups (Trochim, 2006); hence, I desired to interpret reality from the participants' view in order to expose and confront the underlying meaning of scientific events, activities and behaviours. The way the individual in-service teachers approach scientific concepts during lesson execution is overwhelmingly different due to the hidden nature of various components of the PCK construct (Mavhunga, 2014). Therefore, it was necessary adopt the interpretivist philosophy to understand the tacit nature and mental picture of PCK of individual in-service teachers by Mazibe et al. (2018). In this study I worked closely with the research participants in order to understand and interpret their actions from an interpretivist point of view (Tan et al., 2003). An intervention was designed and developed with explicit emphasis on the different components of topic-specific PCK as proposed by Mavhunga and Rollnick (2013). The four TSPCK components used in this study are namely: curricular saliency, learner's prior knowledge fused with what is difficult or easy to teach, representation, and conceptual teaching strategies. The intervention was meant to probe as well as prompt the in-service teachers to formulate their own ways of revealing their knowledge of integrating PCK components while teaching EMI to the Grade 11 learners.

To investigate learners' performance, the positivist stance was adopted in this study because it places more emphasis on empirical evidence and data, thus providing a highly objective form of assessment. The main argument posed by Patton (2002), about the positivist stance used in quantitative research is that the reality of objective, replicable and generalisable data can only be extracted through quantitative observations and measurements. Furthermore, it relied heavily on tests (ie in this case baseline and post-test), and the use of statistical tools, thus enabling easier comparisons and analysis of learner performance. This would ultimately eliminate a biased and subjective outcome. From a positivist school of thought, the statistical analysis process based on the post-test data from this study would also be more consistent, replicable, reliable, verifiable, and generalisable.

3.3 THE MIXED METHODS APPROACH.

The research problem required a mixed methods approach with learner performance constituting quantitative data and PCK data extracted from treatment group teachers constituting qualitative data. According to the Social Sciences Research Laboratories, (2018), the mixed methods approach entails methodological triangulation which is simply a combination of quantitative and qualitative research approaches useful in extracting research data.

Creswell (2014) defines mixed methods research as the type of empirical research method which involves collecting and interpreting both qualitative and quantitative data for purposes of getting greater scope and research corroboration. The mixed methods approach was advocated for in this study to enable reality construction through involvement of research participants (Guba & Lincoln, 1994). The researcher felt obliged to use the mixed methods approach in this study since it involved the pragmatic decision of the researcher to collect, integrate, and analyse both qualitative and quantitative data (Teddlie & Tashakkori, 2009). In this study, qualitative and quantitative data was collected sequentially. Furthermore, the mixed methods approach has been adopted in this research due to its genuine scope of utilising both numbers (*quantitative*) and words (*qualitative*) during data collection, interpretation, and analysis (Datta, 1997). In other words, the mixed methods approach provides the potential for greater depth of generalisable information which might be difficult to achieve if only a single approach was isolated for use (Teddlie, & Tashakkori, 2009).

The researcher managed to gain an in-depth understanding of the context of qualitative findings obtained from teachers and associate it with learner performance that arose from the quantitative data, hence, the researcher decided to adopt the mixed methods approach to address the inevitable limitations and uncertainties practically associated with post-positivist or interpretivist as single methods. In other words, the quantitative and qualitative elements in the mixed methods approach complement each other.

3.4 RESEARCH DESIGN

To extract qualitative and quantitative data, a mixed methods case study design combined with a two-group, pre-test, post-test design was adopted. Eight schools within the same educational district participated in the study. The schools were allocated to two groups, four schools per group. The assigning of sampled schools into experimental and control groups

each was conducted by matching schools according to the pre-test results to ensure equivalent performance levels in Grade 11 Physical Sciences prior to the intervention.
The case study approach focused on four Grade 11 teachers from schools of the experimental group. This allowed collection of qualitative data to explore the PCK development of each teacher. According to Creswell (2009), a case study represents an in-depth study primarily targeting each case separately in order to determine how the sampled participants derive meaning of a phenomenon in its original context. The qualitative data was collected from teachers of the experimental group in the following sequence:

- Before the intervention, the teacher participants from the treatment group were requested to complete a CoRe tool on EMI. This CoRe was referred to as the pre-CoRe during data analysis (see Chapter 4).
- After the intervention, the in-service teacher participants from the treatment group were again requested to complete the CoRe tool (post-CoRe) on EMI followed by their usual lesson preparation. The completion of the post-CoRe tool was conducted prior to lesson planning and preparation in order to raise in-service teachers' alertness pertaining to the components of PCK related to Grade 11 EMI. This assisted them to make pedagogical decisions about the teaching of the topic.
- Video recorded lesson observations were carried out for teachers from the experimental group for the topic of EMI.
- A semi-structured VSR interview session was conducted with the teachers from the treatment group after the lesson observations in order to reflect on the impact of PCK intervention on their teaching of EMI.
- A semi-structured interview (SSI) session was conducted at each of the treatment group teachers' schools a few days after the post-test had been administered.

To explore the learners' performance, a non-random, quasi-experimental baseline-test or post-test control group design was followed (Richardson, 2012). Quantitative data was collected from all learners of the eight participating schools. Prior to the intervention, they wrote a baseline test on a topic (Grade 11 Mechanics) that was taught earlier. These results were used to allocate the schools into two groups, by matching performances of schools. After the teaching of EMI was completed, all wrote a post-test based on EMI. The national senior certificate (NSC) examination rules and regulations were strictly adhered to in both tests. These quantitative results assisted in responding to research sub-question III.

For the purposes of this study, learners remained in their normal classes into which they were assigned by their schools at the beginning of the academic year and with the same teacher in each of the schools. No alterations or deviations were instituted to each school's teaching timetable, pacesetters, annual teaching plans and number of learners in each class. During the study, the teaching of Grade 11 Physics section of EMI was treated in line with the national annual teaching plan and in accordance with the timetable of the school. The researcher did not alter the programmes of the sampled schools. The only exception was the teachers' integration of the PCK intervention methods when teaching EMI to the Grade 11 learners in the treatment group schools.

Meanwhile, the teachers in the control group proceeded with their usual teaching approach and no data was collected from these teachers. However, the learners from the control groups also participated in the post- test. The research design described above is presented diagrammatically in figure 3.1.

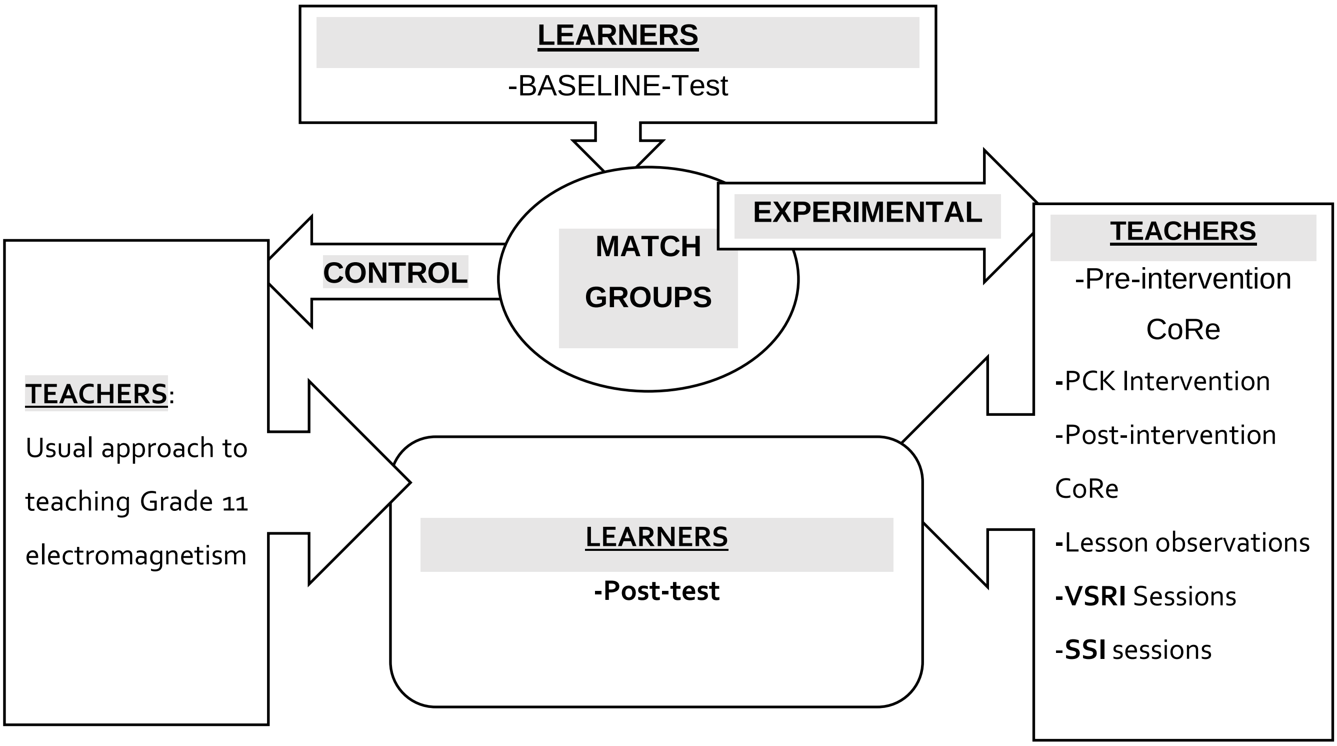


Figure 3.1: Research design. Source: researcher's own.

3.5 SAMPLING OF PARTICIPANTS

According to Rogers (2008) sampling is a method used to statistically select participants for a research study. The researcher's accessibility and convenience should be considered during sample selection (McMillan & Schumacher, 2010).

The targeted population of this research were all Grade 11 Physical Sciences teachers in Mpumalanga province and, all Grade 11 Physical Sciences learners taught by these teachers. The invitation to participate in the study was extended to all schools in a district accessible to the researcher. Eight schools were selected based on the easy accessibility to the researcher and the schools' willingness to participate. The treatment group schools were anonymously identified as E1, E2, E3 and E4. Table 3.1 shows demographic information of teachers from the treatment group who were anonymously identified as TE1, TE2, TE3 and TE4.

Table 3.1: Demographic information of treatment group teachers.

TEACHER	RACE	AGE-RANGE (YEARS)	GENDER	QUALIFICATIONS	SUBJECTS MAJORED	TEACHING EXPERIENCE (YEARS)
TE1	Black	31-35	F	B Ed	PHSC	6
TE2	Indian	51-55	M	B Ed; M Ed	PHSC & MATH	15
TE3	Black	26-30	M	B Ed (hons)	PHSC	6
TE4	Black	25-30	F	B Ed	PHSC	2

3.6 THE INTERVENTION WORKSHOP

Bobo et al. (1991) suggested that the duration of workshops can vary from as little as 60 minutes or even less to as much as a full day or more. Boylan et al. (2018) advocated for a workshop time-frame sufficient to provide participants with opportunities which will be consistent in generating new knowledge. Telese (2008) noted that excessive time for workshop training might lead to insignificant effect in practicality, Kennedy (2016) observed some inconsistency in the duration of professional development workshops used by researchers. Carpendale et al. (2021) pointed out that the inconsistencies could be a result of contextual factors such as teachers` experiences, flexibility, and ability to adapt.

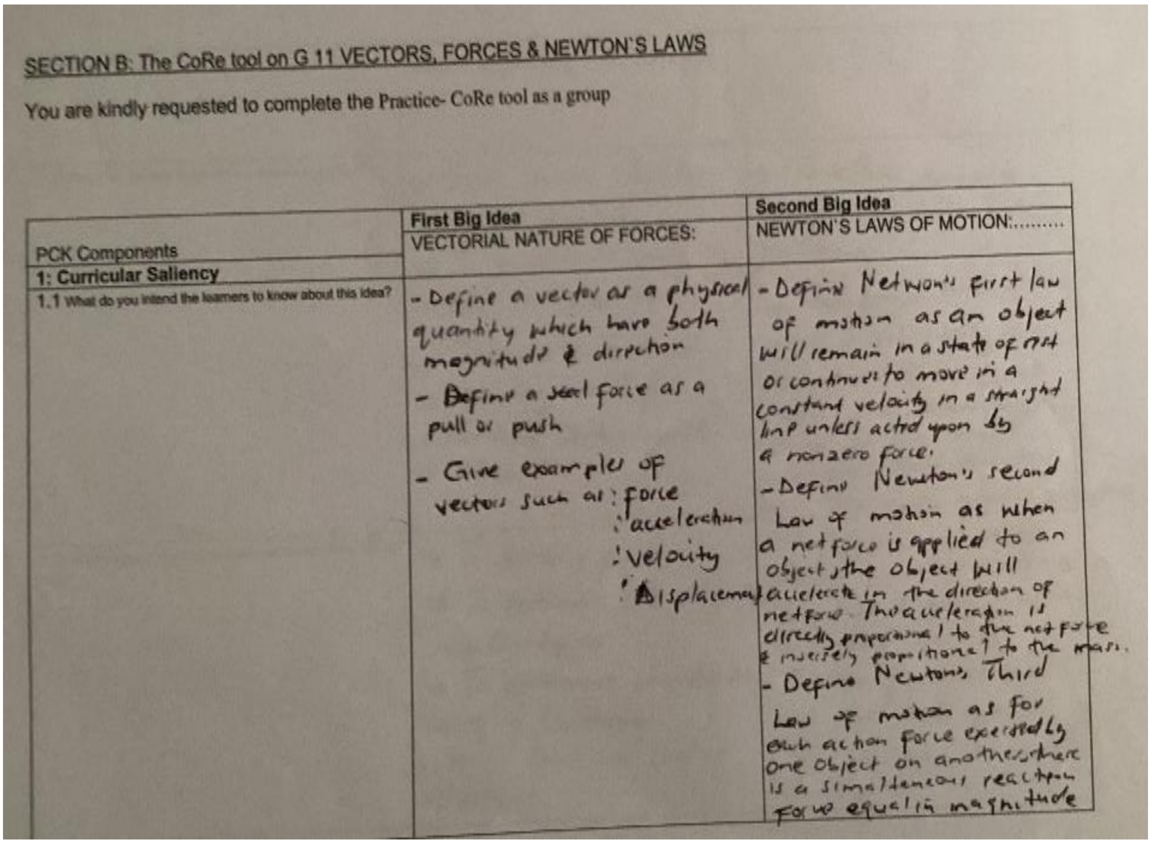
Teachers from the treatment group schools were invited to attend the intervention in the format of a mini workshop which was led by the researcher. The mini workshop was held at a teacher's centre after schooling hours. The workshop took approximately two hours, and it was held from 14:30 to 16:30. All four teachers from the experimental group schools were present.

The workshop focused on the structure of the content representation (CoRe) tool and its elements, without referring to a specific topic. In his presentation, the researcher started by explaining and clarifying the main purpose of the study and responded to concerns from the teacher participants. The CoRe tool was distributed to all teacher participants (see Appendix B). The researcher then went on to explain PCK as a construct and clarified each of the PCK components as presented in the CoRe tool, without referring to the topic of EMI. Additional emphasis was placed on the importance of PCK development as part of professional growth. The notion of 'big ideas' and 'prompts' were discussed thoroughly. It served to assist the teachers on how to complete the CoRe tool. Furthermore, the researcher completely refrained from using examples from EMI while discussing the CoRe tool. Instead, the researcher opted to use examples from other familiar topics such as circuits or forces or equations of motion.

The researcher clarified and emphasised the importance of each PCK component during teaching and learning. Furthermore, the researcher familiarised the teachers with the CoRe scoring rubric which was adopted to score the teacher participants. The intervention session was video recorded for the sake of treatment fidelity.

To be convinced that teacher participants had understood how to use the CoRe tool, the researcher requested them to work in pairs to complete the CoRe tool based on a previously completed Grade 11 topics. The topic prescribed to the teachers during the workshop was Newton’s laws of motion. It took on average 38 minutes for teachers to complete the intervention CoRe tool. Forces and Newton’s laws were chosen as the big ideas needed when completing the intervention CoRe tool.

After the completion of the CoRe tool, the two pairs of teachers then regrouped to discuss what they thought should be included or excluded. Figure 3.2 presents an excerpt of teachers’ combined efforts of what they suggested for the component curricular saliency in response to the prompt “What do you intend learners to know about this idea?” based on Newton’s laws.



SECTION B: The CoRe tool on G 11 VECTORS, FORCES & NEWTON`S LAWS

You are kindly requested to complete the Practice- CoRe tool as a group

PCK Components	First Big Idea VECTORIAL NATURE OF FORCES:	Second Big Idea NEWTON`S LAWS OF MOTION:………
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	- Define a vector as a physical quantity which have both magnitude & direction - Define a [illegible] force as a pull or push - Give examples of vectors such as: force : acceleration : velocity : Displacement	- Define Netwon's first law of motion as an object will remain in a state of rest or continues to move in a constant velocity in a straight line unless acted upon by a nonzero force. - Define Newton's second Law of motion as when a net force is applied to an object, the object will accelerate in the direction of net force. The acceleration is directly proportional to the net force & inversely proportional to the mass. - Define Newtons Third Law of motion as for each action force exerted by one object on another, there is a simultaneous reaction force equal in magnitude

Figure 3.2: Snapshot of part of the completed Intervention CoRe tool during intervention. Source: Researcher's own.

Further discussions were held based on how teachers had completed the CoRe tool based on Newton's laws. The researcher addressed all the questions which were posed by the teachers regarding PCK components and the associated CoRe prompts.

The researcher concluded the intervention workshop by requesting the educators to individually complete the post-intervention CoRe as part of their routine lesson preparations for teaching the EMI lessons. The big ideas of Magnetic flux (MF) and Faradays' law (FL) were to be used in the CoRes.

3.7 QUALITATIVE DATA COLLECTION AND INSTRUMENTS

The qualitative data for the control group teachers were not needed. Changes in their PCK was not anticipated because they did not undergo the intervention. Furthermore, observing 4 more teachers would be logistically difficult as curriculum topics are scheduled to be taught in specific weeks of the school year, making it challenging for the researcher to fit in all observations in 8 different schools.

3.7.1 PRE-INTERVENTION CoRe

The researcher constructed a questionnaire based on the CoRe prompts, applied to the topic of EMI. This questionnaire is referred to as the pre-CoRe. The teachers from the treatment group completed the pre-CoRe in their own time at home, prior to the intervention. The qualitative data from the pre-CoRe was needed to assess each teacher's PCK before intervention. The pre-CoRe data acted as a point of reference to track the teachers' PCK development in the topic of EMI during the study. The pre-intervention CoRe was presented in a question format because the teachers had not encountered CoRes at this stage of the research. Hence, it was possible that the complex tabular format of the CoRe as suggested by Loughran et al. (2004) and used in the post-CoRe, might have been a challenge prior to intervention.

3.7.2 THE POST-INTERVENTION CoRe

After the intervention, all teachers from the treatment group were requested to construct CoRes that were based on the big ideas of magnetic flux (MF) and Faraday's law (FL). This was followed by their usual lesson preparation. The constructed post CoRes were considered as a representation of the teacher's personal PCK about EMI after the intervention. Furthermore, the teachers' post-CoRes were analysed and compared with the score for their pre-CoRes to track the development of their pPCK, addressing the first research sub-question.

3.7.3 VIDEO-RECORDED LESSONS

All the lessons on EMI taught by the teacher participants from the treatment group were video-recorded to capture information regarding the teachers' enacted PCK, related to the big ideas of MF and FL. The video or audio-recordings were transcribed and analysed by the researcher. Furthermore, the teachers' enacted PCK scores were later analysed and compared with their personal PCK, addressing the second research sub-question.

3.7.4 VSR INTERVIEW SESSIONS

The teacher participants from the treatment group were scheduled for video-stimulated recall (VSR) interview sessions after lesson observations. A VSR interview is a research technique which provides the researcher and the teacher with time to reflect by revisiting the recorded classroom scenes in order to get a direct link and dialogue between the teachers' theory and practice (Reitamo & Sim, 2010).

The purpose of the VSR interview (VSRI) was to get interpretive and informative data regarding the in-service teacher's reflection on their enacted PCK, related to Grade 11 EMI. The VSRI sessions were audio-recorded, and teachers were requested to verbally respond to the open-ended questions based on their lesson. The prepared semi-structured questions encouraged teachers to disclose their beliefs situated in their EMI pedagogical reasoning and skills as well as account for their actions during the lesson. This consequently assisted in extracting qualitative data about teachers' PCK and provided some information which assisted in scoring their enacted PCK to respond to the second research sub-question.

3.7.5 THE SEMI-STRUCTURED INTERVIEW SESSIONS

A semi-structured interview (SSI) session was conducted at each of the treatment group teachers' schools a few days after the post-test had been administered to the learners. The purpose of the SSI session was to obtain interpretive and informative data regarding the teacher's teaching approach and experiences on enacted PCK, more specifically related to Grade 11 EMI. The SSI session was audio-recorded, and teachers were requested to verbally respond to the open-ended questions which assisted in scoring each of the treatment group teachers' enacted PCK.

3.8 QUANTITATIVE DATA COLLECTION AND INSTRUMENTS

3.8.1 BASELINE-TEST

Prior to the intervention period, a total of 411 Grade 11 learner participants from the eight sampled schools wrote a baseline-test based on mechanics. The test was set by the researcher, moderated and validated by SMEs in Physics and Physical Sciences subject advisors. The baseline test instrument consisted of 20 multiple-choice questions (MCQ). These were based on prior knowledge about Newtonian mechanics, since it was the section which they had just covered in the first term prior to electromagnetism. The test involved most of the expected learning outcomes on forces and vectors in line with the Grade 11 examination guidelines and CAPS document.

The baseline test results were used for allocation of schools to treatment and control groups by matching schools to minimise group differences. In other words, the two groups were to be equivalent regarding their performance in Grade 11 Physical Sciences before intervention. Learners were expected to respond to all questions within the specified time frame. The baseline test was administered at the same time in all the sampled schools. Marking and capturing of results was conducted by the researcher.

3.8.2 POST-TEST

After the teaching of EMI was completed, a total of 411 Grade 11 learner participants from the eight sampled schools wrote a post-test. The test was set by the researcher and validation was conducted by SMEs in Physics. The researcher constructed the post-test based on EMI in line with the South African Grade 11 syllabus. The test was aligned to the Grade 11 examination guidelines (DBE: Grade 11 examination guidelines, 2015: 12), CAPS documents (DBE, 2011: 86-88) and textbook sources (Kelder et al., 2016: 160; Olivier, 2017: 254; Horner & Williams, 2012: 346; and Broster et al., 2017: 216). The question paper consisted of 20 multiple-choice questions as well as four open-ended questions. Learners responded to all questions within the specified time frame. The post-test was administered by the teachers at the same time in all the sampled schools. Marking and capturing of results was conducted by the researcher. The researcher looked for the footprint of the teacher's enacted PCK in the learners' answers to the post-test. The quantitative data collected from the post-test assisted in responding to the third research sub-question.

3.9 QUANTITATIVE DATA ANALYSIS

The performance of the two groups in the pre-test were compared to check if the two groups could be regarded as similar prior to the intervention, using hypothesis testing. The null hypothesis was formulated as follows:

> ***H_0:*** *There is no statistically significant difference between the performance of the control group and the experimental group.*

The performance of the groups in the post-test was quantitatively analysed to establish if there were significant differences between the treatment and the control groups, which would be ascribed to the impact of a teacher's PCK on learners' level of performance in EMI.

A t-test was considered for hypothesis testing. However, t-test limitations exist in most experimental studies, and this had to be acknowledged. Therefore, before implementation of the independent samples t-test, the assumptions had to be checked for the baseline test as well as for the post-test. These assumptions are discussed in Chapter 5. If some of these assumptions were violated, alternative tests were considered. The main purpose of quantitative data analysis was to see if there was a statistically significant difference in post-test performance of the treatment and control groups.

3.10 QUALITATIVE DATA ANALYSIS

Mavhunga and Rollnick (2013) advocated for five PCK components to enhance the teaching quality namely, teachers' knowledge of Curricular saliency, learners' prior knowledge, what is difficult or easy to teach, conceptual teaching strategies and representations. Coetzee's (2018) rubric is based on these five components. The researcher started analysing teachers' PCK using Coetzee's (2018) rubric but then discovered that the teachers' responses on *Learner's prior knowledge* and *what is difficult or easy to teach* were intertwined. The responses involved misconceptions in prior knowledge as well as misconceptions in the new content. It was difficult to score these two components. The researcher therefore decided to merge these two components into a new component *Learner understanding*, similar to Vollebregt (2020). The adapted rubric can be found in Appendix G.

The rubric for scoring teachers' personal and enacted PCK was on a four-point scale namely *Limited* (**L**), *Adequate* (**A**), *Developing* (**D**) and *Exemplary* (**E**). Each of the descriptors for the four levels was based on Grade 11's EMI big ideas of MF and FL, hence the treatment group teachers' pre-CoRes, post-CoRes and enacted PCK were all evaluated and scored based on the rubric adapted from Coetzee (2018) (see Appendix G).

An interpretive qualitative approach was used to analyse and score the teachers' responses to the pre- and post- CoRe according to the rubric based on the effectiveness of designing CoRes of Grade 11 EMI. The video-recordings of lesson observations and VSR recordings of interviews were analysed and interpreted qualitatively to establish the extent to which teachers could enact PCK in teaching Grade 11 electromagnetism, using the same rubric as for personal PCK.

The scores from each teacher's pre-CoRes and post-CoRes were later compared to see if the intervention had a noticeable impact on a teacher's personal PCK. Next, the scores for enacted PCK were compared to scores for the post-CoRe to explore how well teachers enacted their personal PCK. One of my research supervisors checked all evaluations and discussions were made to reach consensus to resolve different scores.

In order to conduct a quantitative comparison, the PCK scores were then represented on a numerical scale of 1 to 4, where 1 = limited, 2 = adequate, 3 = developing and 4 = exemplary. The pre-CoRe numerical scores were then added and compared to the post-CoRe numerical scores. Average scores were calculated for enacted PCK scores per teacher and compared to the post-CoRe average scores. In this way, the development of PCK could be represented numerically for each teacher.

3.11 VALIDITY AND TRUSTWORTHINESS OF DATA

Johnson (1997) conceptualised validity as trustworthiness, quality and rigour of data in order to eliminate bias and maximise the truthfulness, dependability and credibility of research findings. Therefore, validity eliminates bias to improve the generalisability of the research findings (Denzin & Lincoln, 2017).

Crystallisation is a strategy used to improve the validity or trustworthiness (Maree, 2010) of research while evaluating the research findings. To improve the analysis, understanding and diverse construction of realities regarding the impact of a PCK intervention in Grade 11 electromagnetism, crystallisation was conducted since multiple data collection methods were involved in this study. Crystallisation is a technique, to arrive at a conclusion from various data sources. This is like Chemistry, where the dissolved substance within the data precipitates from the data and becomes visible. The qualitative data collection instruments were the pre- and post-intervention CoRe tools, and video-recorded lesson observations, VSRI sessions and SSI sessions. The researcher used Coetzee's (2018) rubric (see Appendix G) which was standardised through the use of Rasch analysis and adapted it to be slightly in line with the grand rubric following Vollebregt (2020). To validate the scoring of PCK, the researcher engaged with peer PCK researchers for expert validation of the scores based on the rubric and other data gathering instruments that were used for qualitative data collection.

The baseline test and post-test were used as the quantitative data collection instruments. Both the baseline and post-tests were set by the researcher while being guided by the CAPS document and Grade 11 Physical Sciences examination guideline. The researcher engaged with peer researchers, subject advisors and SMEs for expert validation of quantitative data collection instruments (baseline and post-test) and data interpretation. Furthermore, the baseline and post-test instruments were thoroughly pre-moderated by the SMEs and subject advisors to ensure their CAPS compliance. They were piloted for use prior to their administration by the sampled schools.

3.12 ETHICAL CONSIDERATIONS

To proceed with the study, the researcher obtained ethical clearance from the Ethics Review Committee of the University of Pretoria. This step ensured that the research conducted by any University of Pretoria (UP) student complied with the protection of human subjects' rights as well as allowing due process to be followed. The request for official permission to conduct research in the sampled schools was granted by the Head of Mpumalanga Department of Education (see Appendix J8). Additionally, the researcher's request for permission to conduct research in schools under two circuits was granted by circuit managers and school principals. The researcher proceeded with the study immediately after receiving letters of approval from the above-mentioned officials of the Mpumalanga Education Department.

Ethical considerations were followed during the entire period of study. From the sampled schools, all Grade 11 Physical Sciences learners and their teachers were invited to participate. Learners and parents were requested to give their consent before participating in the study. Those learners whose parents did not give consent to participate in the research activities were excluded from participation. During video-recording, these learners were seated on one side of the classroom to ensure that they were not captured on video. During lesson observation sessions, the researcher sought the consent of one of the learners from each of the participating classes at each of the sampled schools to video record the lesson based on MF and FL. The researcher guaranteed all the participants that the information captured during the study was to remain strictly confidential and learners' faces were not to be captured. The video-recorded data was to be used specifically for academic purposes. Every participant was free to withdraw at any time during the study. The anonymity of all research participants was prioritised.

3.13 IMPACT OF COVID-19

The 2020 academic year was associated with Coronavirus disease 2019 (COVID-19); an acute respiratory contagious disease declared by the World Health Organization (WHO) as a global pandemic. Millions of people globally were infected while millions lost their lives. The education sector was not spared from the unusually strict health conditions which needed to be adhered to. This occurred during the same period when this study was conducted. The findings from this study depended on the psycho-social co-operation of research participants, since the psychological impact of COVID-19 on every individual cannot be ruled out. Hence, this might have compromised the quality, validity and credibility of research findings to some extent.

The researcher made the study feasible, working within the confines of the CAPS document and the revised national annual teaching plans. Furthermore, training teachers during intervention, and lesson deliberations and observations had to proceed while strictly adhering to all health and ethical protocols.

3.14 SUMMARY OF CHAPTER 3

This chapter started by presenting the research questions which were to be answered based on the findings of this study. The researcher went on to focus on epistemological and ontological aspects of the research. A description of the research design was presented and aided by a flow diagram. The sampling approach to suit the mixed methods case study research design was then discussed. Details of how the intervention was conducted were provided. The multiple data gathering instruments which were used in this mixed methods research approach were discussed. The methods and philosophy behind *qualitative and* *quantitative data analysis methods* and *validity and reliability* and how it relates to this study was presented in this chapter. Additionally, the ethical considerations underpinning the entire scope of this study were thoroughly discussed. An additional section related to the probable impact of COVID-19 on the research participants was presented.

CHAPTER 4: DATA ANALYSIS FOR TEACHER PARTICIPANTS

4.1 INTRODUCTION

In this chapter the researcher presents the qualitative results of the study.

The findings from qualitative data assisted in responding to sub-questions I and II, namely:

I. What is the influence of the intervention on the teachers' personal PCK?
II. To what extent is the teachers' personal PCK manifested in the enacted PCK?

The results from the teacher participants of the experimental group are presented and discussed per teacher. For each teacher, the data analysis is presented in the sequence of data collection. Before the intervention each teacher completed a pre-intervention CoRe questionnaire based on EMI. After the intervention, each teacher was requested to complete the post-intervention CoRe as part of their lesson preparation for Grade 11 EMI. For the post-CoRe, the two big ideas 'Magnetic flux' (MF) and 'Faraday's Law' (FL) were provided by the researcher. Next, lessons on EMI were observed and video-recorded. After the lesson observations, VSRI sessions were held with each teacher, followed by a final interview, the SSI session. The scoring was conducted using the rubric (Appendix G) adapted from Coetzee (2018).

4.2 THE CASE OF TEACHER TE1.

Teacher TE1 is a female in her early 30s. She obtained a Bachelor of Education (B.Ed.) degree from one of South Africa's public universities and, majored in Mathematics and Physical Sciences. She joined the teaching fraternity as a Grade 10 Mathematics teacher five years prior to the time the data was collected. Teacher TE1 became permanently employed at her current rural secondary school where English is the language of instruction across the curriculum. The school where she is working is one of the high-enrolment Mathematics, Science, and Technology academy (MSTA) schools in Mpumalanga province. The school enrols from Grade 7 to Grade 12. At the time when this study was conducted, the school had an overall enrolment of approximately 900 learners, and TE1 was involved in teaching four Grade 11 Physical Sciences classes each with 49 learners.

However, she only started teaching Physical Sciences to Grade 10s in 2020. In 2021, she was accorded the chance to teach Physical Sciences to the same learners who were by then in Grade 11. In other words, at the time when this study was conducted, she was in her first year of teaching Physical Sciences to the Grade 11 learners. The teacher mentioned during my first visit to her school that she would need at least three periods to complete the Grade 11 topic of electromagnetism. She remarked that her ability to complete the topic depended on the effectiveness of teaching strategies and, how such strategies would be translated into her learners' ability to understand. For the sake of this study, only one of her lessons in one of her four Grade 11 classes based on EMI was video recorded. The findings based on teacher TE1 on how she approached Grade 11 EMI are outlined in the following sub-sections from 4.2.1 to 4.2.8.

4.2.1 PRE-INTERVENTION CoRes

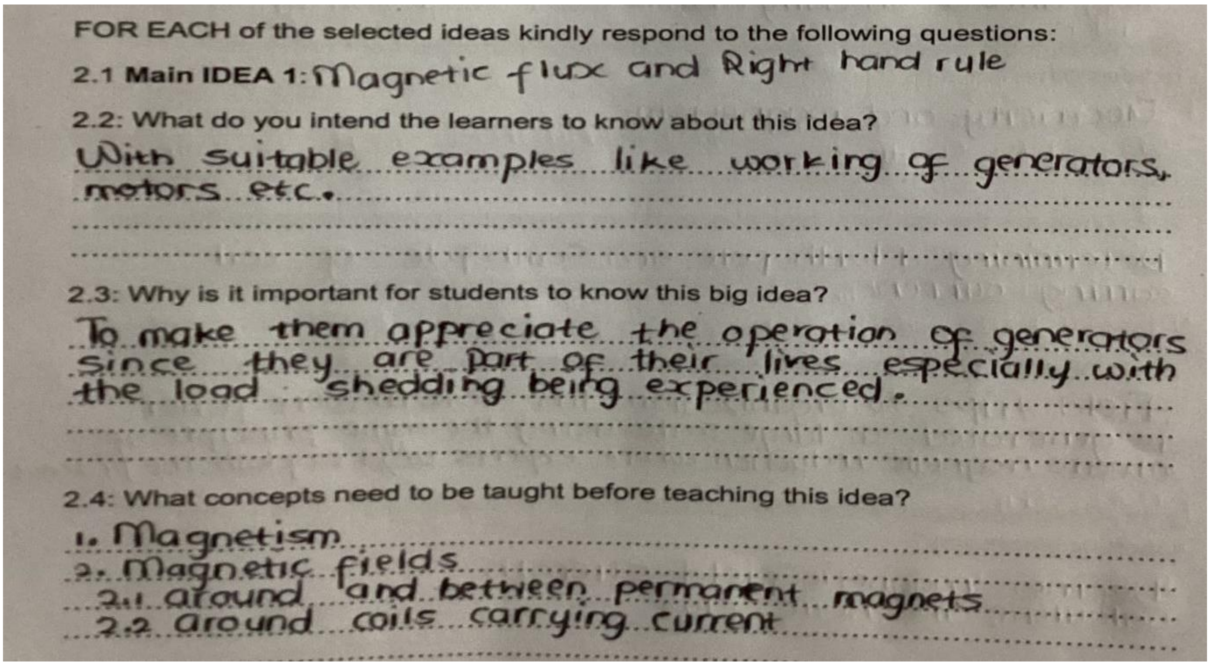
TE1 responded to all sections of the pre-intervention CoRe, shown in Appendix **A1**. Table 4.1.1 shows the scores obtained after a thorough scrutiny of responses, separately for each of the big ideas of MF and FL. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components

Table 4.1.1: Scores of TE1 based on pre-CoRes in the big ideas of magnetic flux (MF) and Faraday's law (FL)

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency	x			o				
2	Learner Understanding	x	o						
3	Conceptual teaching strategies	x			o				
4	Representations			x	o				

4.2.1.1 KNOWLEDGE OF CURRICULAR SALIENCY

Although there is some available evidence of knowledge about sequencing or scaffolding, most of the statements from the completed pre-intervention CoRes seem to be general statements. TE1 lists the main ideas based on the headings in the CAPS document. Even her subordinate ideas are limited only to being aware of the definitions of terms such as MF, FL and calculations using formulae.



FOR EACH of the selected ideas kindly respond to the following questions:

2.1 **Main IDEA 1:** Magnetic flux and Right hand rule

2.2: What do you intend the learners to know about this idea?

With suitable examples like working of generators, motors etc.

2.3: Why is it important for students to know this big idea?

To make them appreciate the operation of generators since they are part of their lives especially with the load shedding being experienced.

2.4: What concepts need to be taught before teaching this idea?

1. Magnetism
2. Magnetic fields
  2.1 around and between permanent magnets
  2.2 around coils carrying current

Figure 4.1.1: Snapshot showing TE1’s answers on the first big idea of MF prior to intervention. Source: Researcher’s own.

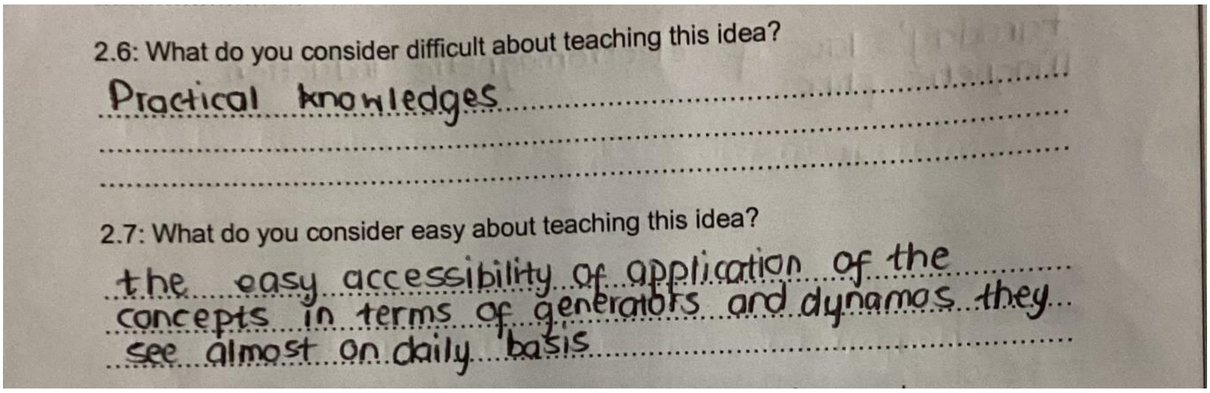
The identified pre-concepts such as magnetism only refer to elementary concepts generally regarded as basic to the section of EMI (see Figure 4.1.1). She listed the right-hand rule (RHR) together with MF as new content in question 2.1, while it should have been taught earlier with electromagnetism according to the curriculum. Reasons provided as to why it is important for learners to know about MF mostly refer to applications of EMI and were ‘limited to the general benefit of education’, as stated in the rubric. The reasons were not necessarily meant to develop their understanding of the concepts, hence her personal PCK (pPCK) for the curriculum saliency (CS) component based on the first big idea of MF is scored as “*limited*”.

For the second big idea of FL, TE1 presented the application of electromagnetism and the statement of FL as concepts that she wants the learners to know. Her reason for why it is important for learners is based on application of EMI to the generation of electricity. Furthermore, the RHR and MF are presented as a concept to be taught prior to FL. However, the *application* of the RHR to predict the direction of the induced current should have been included as new knowledge to be known by learners. ‘There is no indication that attention was paid to proper sequencing’ as described in the rubric. Instead, the RHR was regarded as concept to be taught prior to teaching FL while Lenz’s law was presented in question 3.5 as something which she knew and did not intend her learners to know about it yet. ‘Knowledge of curriculum is not evident’ as stipulated in the rubric. Hence, her pPCK for this CS component based on FL is scored as ‘*adequate*’

4.2.1.2: KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the pre-concepts mentioned are not adequate for the first big idea of MF. The teacher indicates electricity and magnetism, and magnets and magnetism respectively as the pre-requisite ideas to understand MF and FL. The way the ideas are presented is somehow vague and incomplete. The teacher presents common errors such as their inability to identify north pole and south pole of a coil-carrying current as a misconception regarding the first big idea of MF.

In figure 4.1.2, the teacher seems to generalise the answer to the question of 'What do you consider to be difficult about teaching this idea'. In her response to this prompt, she presents a broad issue of 'practical knowledges' as a challenge without identifying and specifying the actual ideas about flux that are problematic.



2.6: What do you consider difficult about teaching this idea?

Practical knowledges

2.7: What do you consider easy about teaching this idea?

the easy accessibility of application of the concepts in terms of generators and dynamos they see almost on daily basis

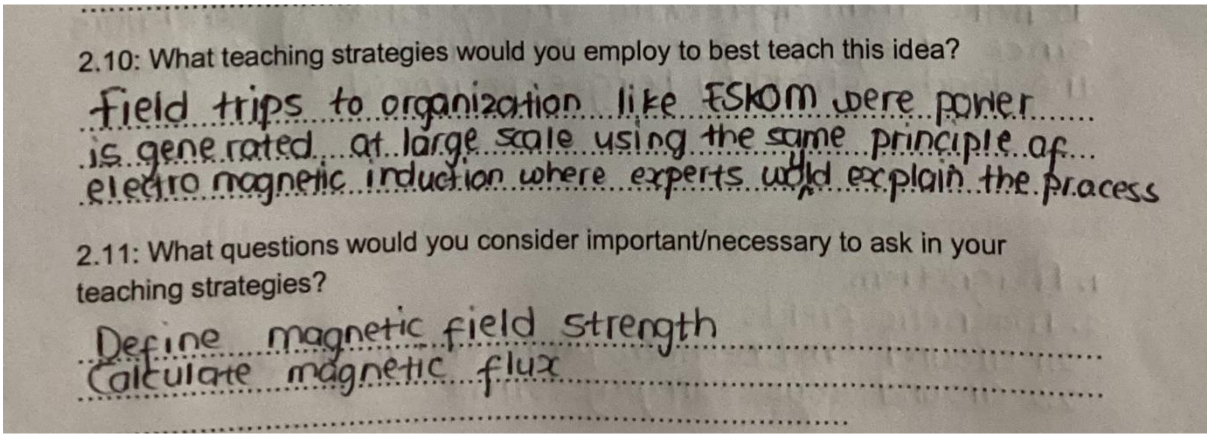
Figure 4.1.2: Snapshot showing TE1's answers related to 'learner understanding' about the big idea of MF prior to intervention. Source: Researcher's own.

Furthermore, the teacher provides inappropriate and inadequate reasons of what makes teaching such a topic easy, referring again to generators. These are not relevant as generators are not taught in Grade 11, but rather in Grade 12 according to the CAPS curriculum. TE1 assumes that all learners are technically exposed to the functionality of generators and dynamos in their everyday lives. The pPCK for this component based on the first big idea of MF was scored as '*limited*' because of 'broad topics without specifying the actual sub-concepts that are problematic are identified,' as stated in the rubric.

For the second big idea of FL, TE1 indicated the distinction between magnetic flux and magnetic field as a misconception in question 3.9. This cannot be regarded as a misconception in prior knowledge, instead it is a difficulty in the first big idea of MF. Although she did not mention the RHR as prior knowledge needed to apply Lenz's law, she referred to it as part of the content for EMI. Furthermore, theTE1 presents application of Lenz's law as a response to question 3.6. She does not provide any further details about what makes it difficult to teach Lenz’s law. Although she mentions Lenz’s law in question 3.5 which she knows but does not want learners to know yet, this provides evidence that her understanding of the link between RHR and Lenz’s law is restricted. The pPCK for this component based on the second big idea of FL was scored as ‘*limited*’ because of ‘knowledge about this component is not evident’ as stated by the rubric.

4.2.1.3: CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, the TE1 talks about ‘field trips to organization like ESKOM as a conceptual teaching strategy (CTS) (see Figure 4.1.3). Surely such enrichment cannot replace teaching the topic of EMI.



2.10: What teaching strategies would you employ to best teach this idea?

field trips to organization like ESKOM were power is generated at large scale using the same principle of electro magnetic induction where experts would explain the process

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

Define magnetic field strength
Calculate magnetic flux

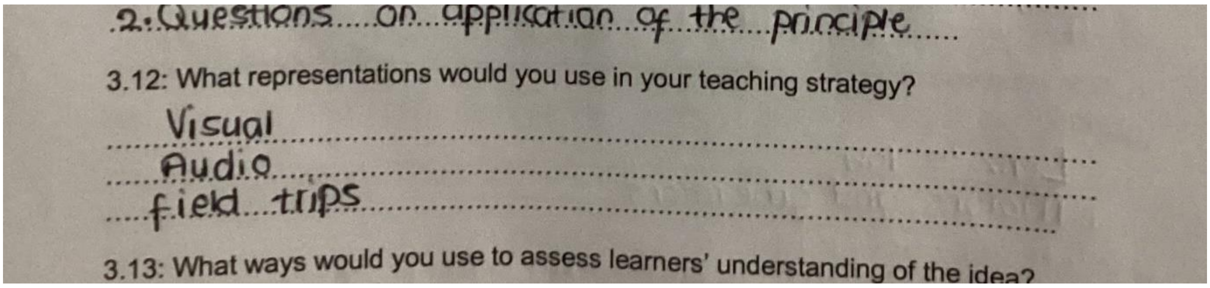
Figure 4.1.3: Snapshot of TE1’s conceptual teaching strategies for the big idea of MF mentioned by TE1 prior to intervention. Source: Researcher’s own.

The suggested questions to be asked during lesson execution are suitable for summative assessment but not for development of concepts. For this component, TE1’s pPCK based on the first big idea was scored as ‘*limited*’ because of ‘a list of general strategies without indications of how they will be employed was given’, as stated in the rubric.

For the second big idea of FL, TE1 correctly suggested a practical demonstration as her CTS in response to question 3.10. Furthermore, she correctly suggested that questions to be asked should also be based on factors affecting the magnitude of induced electromotive force (EMF) as well as application of Faraday’s principle. However, no mention was given about the kind of questions to be asked based on Lenz’s law and RHR application. Therefore, TE1’s pPCK for this component based on the second big idea of FL was scored as ‘*adequate*’ because of ‘the response lacks other aspects of curriculum saliency,’ such as those associated with Lenz’s law and RHR application when teaching the second big idea.

4.2.1.4: REPRESENTATIONS

For the first big idea of MF, TE1 mentioned experiments and diagrams on the chalkboard as the kind of representations to be used. For the second big idea of FL, the teacher listed visual, audio and trips in her pre-intervention CoRe as the representation she would use. Figure 4.1.4 shows how the teacher responded to question 3.12 based on the big idea of FL, as shown in figure 4.1.4



2: Questions on application of the principle

3.12: What representations would you use in your teaching strategy?

Visual

Audio

field trips

3.13: What ways would you use to assess learners' understanding of the idea?

Figure 4.1.4: Snapshot of representations for second big idea of FL mentioned by TE1 prior to intervention. Source: Researcher's own.

'Even though some presentation methods are given, there is no evidence how the use of the representation will lead to increased understanding of concepts', as stated in the scoring rubric. This justifies why her pPCK for both the big ideas of MF and FL were scored as '*adequate*'.

4.2.2 DISCUSSION OF POST INTERVENTION CoRes

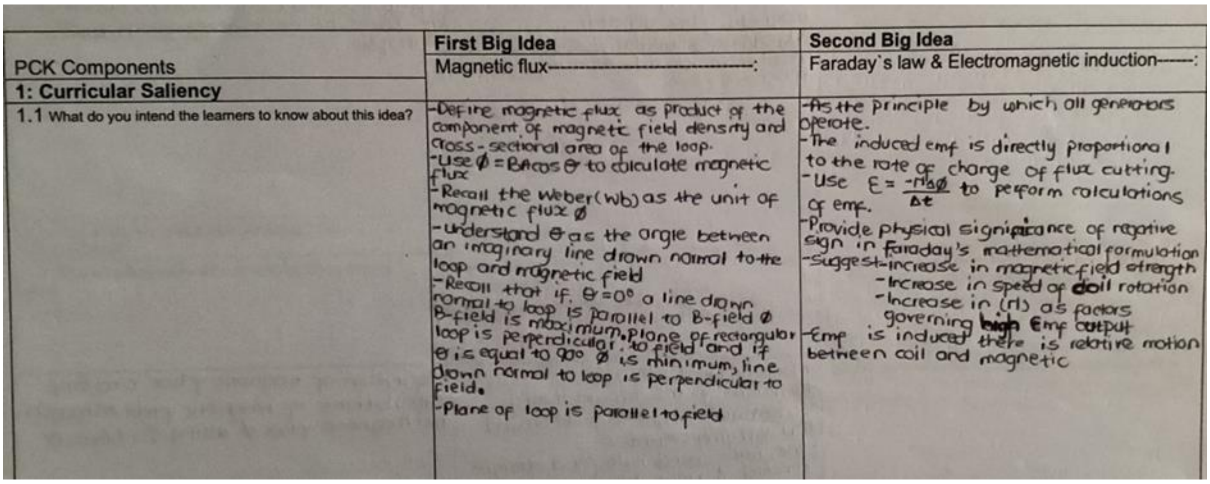
Table 4.1.2 shows the score results obtained after a thorough scrutiny of responses given in TE1's completed post-intervention CoRe based on Grade 11's EMI section of electromagnetism (see Appendix C1). Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.1.2: Scores for TE1 based on post-intervention CoRes.

PCK Component		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency					x	o		
2	Learner understanding				o	x			
3	Conceptual teaching strategies					x	o		
4	Representations					x	o		

4.2.2.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, in figure 4.1.5, the subordinate ideas such as the physical significance of the angle θ and factors governing output of induced EMF which account for the application of the big idea of MF and FL are identified, presented and explained. The formula needed in performing numerical flux calculations is identified, presented and explained. The teacher provides further details to be considered when performing numerical calculations of MF. 'There are indications that attention was paid to sequencing of the ideas' and the teacher 'identified pre-concepts consist of those required to understand the current key idea,' as stated in the rubric, hence, the justifiable score for TE1's pPCK based on the first big idea of MF under this CS component was rated as '*developing*'.



PCK Components	First Big Idea Magnetic flux--------------------------------:	Second Big Idea Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	-Define magnetic flux as product of the component of magnetic field density and cross-sectional area of the loop. -Use $\phi = BA\cos\theta$ to calculate magnetic flux -Recall the Weber(Wb) as the unit of magnetic flux ϕ -Understand θ as the angle between an imaginary line drawn normal to the loop and magnetic field -Recall that if, $\theta = 0°$ a line drawn normal to loop is parallel to B-field ϕ B-field is maximum. Plane of rectangular loop is perpendicular to field and if θ is equal to 90° ϕ is minimum, line drawn normal to loop is perpendicular to field. -Plane of loop is parallel to field	-As the principle by which all generators operate. -The induced emf is directly proportional to the rate of change of flux cutting. -Use $E = \frac{-N\Delta\phi}{\Delta t}$ to perform calculations of emf. -Provide physical significance of negative sign in Faraday's mathematical formulation -Suggest-increase in magnetic field strength -Increase in speed of coil rotation -Increase in (N) as factors governing high Emf output -Emf is induced there is relative motion between coil and magnetic

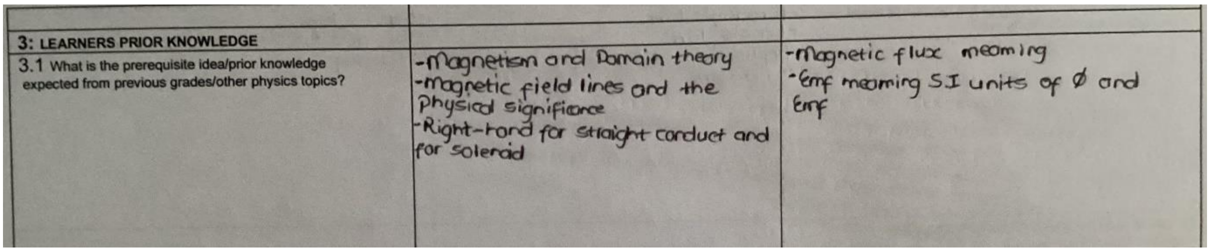
Figure 4.1.5: Snapshot of TE1's curricular saliency for MF (left) and FL (right) after intervention workshop. Source: Researcher's own.

For the second big idea of FL, in figure 4.1.5, TE1 provides EMI as the principle by which all generators operate. She presents Faraday's law statement and its mathematical formulation as well as factors governing EMF output as a 'must know' by her learners in her post-CoRes. TE1 goes further to present flux definition and its associated calculations as prior concepts for the big idea of FL. TE1 indicated the need to provide the physical significance of the negative sign in Faraday's formula but does not attempt to link it to the RHR.

In fact, TE1's list is incomplete; there is no reference to RHR to determine the direction of the induced current or induced field. Furthermore, the teacher response to CS in question 1.3 by referring to application of EMI to the DC and AC generators. Although TE1 has a valid point, the concepts of generators according to the CAPS document is only treated in Grade 12. Suffice to say that although, 'the subordinate ideas that account for the application of equations and definitions are identified, the list of subordinate ideas is not extensive', and exhaustive as stated in the rubric, hence, the justifiable score for teacher's pPCK based on the second big idea of FL of this CS component was rated as '*developing*'.

4.2.2.2: KNOWLEDGE OF LEARNER UNDERSTANDING

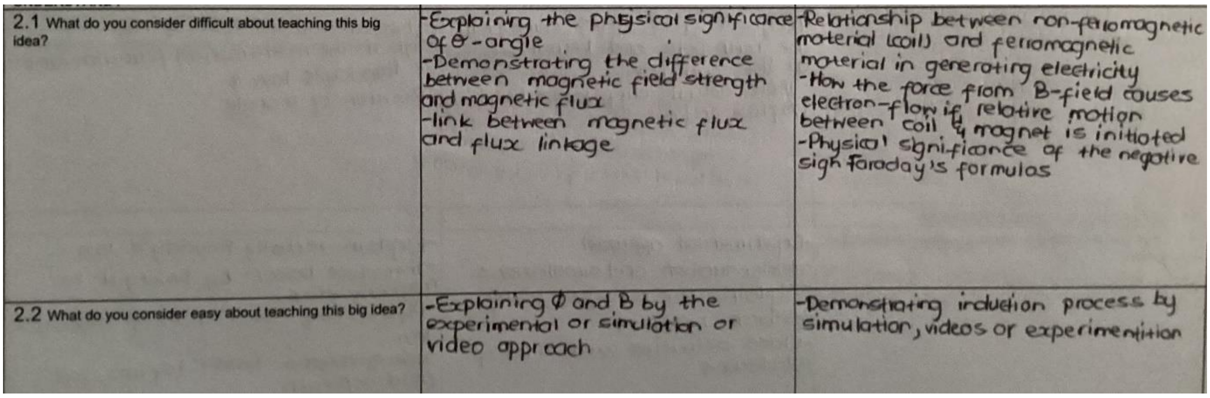
For the first big idea of MF, shown in figure 4.1.6, TE1 provided evidence of knowledge of relevant prior knowledge. In her response to question 3.1, TE1 indicated the magnetism and the domain theory as prior knowledge needed in teaching MF. Magnetic field lines and the RHR were also presented as prerequisites for a learner's conceptualisation of the first big idea of MF.



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	-Magnetism and Domain theory -Magnetic field lines and the Physical significance -Right-hand for straight conduct and for solenoid	-Magnetic flux meaning -Emf meaning S.I units of ϕ and Emf

Figure 4.1.6: Snapshot of TE1's 'Learner prior knowledge' for MF (left) and FL (right) after the intervention workshop. Source: Researcher's own.

In figure 4.1.7, TE1 indicated that it was not easy to demonstrate the difference between magnetic field strength and magnetic flux. TE1 pointed out that providing a convincing explanation of the physical significance of the angle in the flux formula was difficult. Furthermore, TE1 mentioned that the use of the experimental and simulation approach makes the first big idea easy to teach.



2.1 What do you consider difficult about teaching this big idea?	-Explaining the physical significance of θ-angle -Demonstrating the difference between magnetic field strength and magnetic flux -link between magnetic flux and flux linkage	-Relationship between non-ferromagnetic material (coil) and ferromagnetic material in generating electricity -How the force from B-field causes electron-flow if relative motion between coil & magnet is initiated -Physical significance of the negative sign Faraday's formulas
2.2 What do you consider easy about teaching this big idea?	-Explaining ϕ and B by the experimental or simulation or video approach	-Demonstrating induction process by simulation, videos or experimentition

Figure 4.1.7: Snapshot of TE1's 'learner understanding' for MF (left) and FL (right) after the intervention workshop. Source: Researcher's own.

The following are considered as concepts that are difficult to teach in her first big idea of MF:

- the difference between magnetic flux and field strength.
- magnetic flux change and how it relates to field strength and MF.
- the physical significance of relative motion between the magnet and the coil.

The teacher’s pPCK based on the first big idea of MF of this component was scored as ‘*developing*’ because most of the ‘appropriate difficulties for the first big idea were identified and clearly formulated’, as outlined by the rubric.

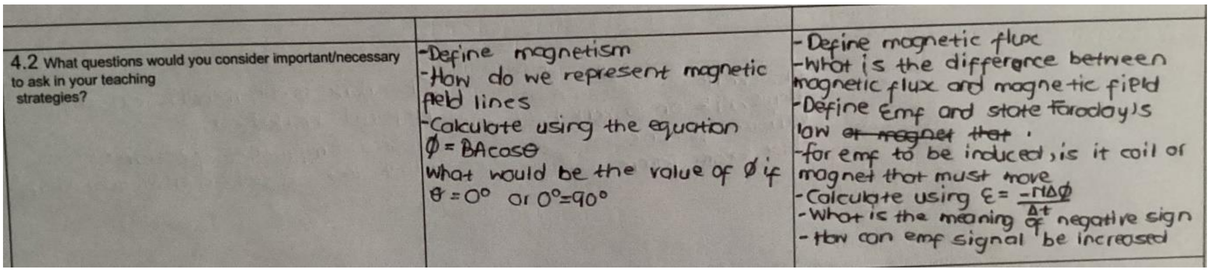
For the second big idea of FL, TE1 identifies the definition of magnetic flux and that of EMF as prior knowledge needed by learners before being taught FL. However, she has not indicated the RHR as prior knowledge needed to determine the direction of induced current for FL, as required by the curriculum. In response to question 3.2, she presents the physical significance of the negative sign in Faraday’s formula as a misconception. Her statement suggests that she is not so sure about what a misconception is. This reveals her own restricted understanding, thus compromising the quality of her personal PCK.

How a magnetic force can drive or cause electron flow in a conductor during EMI was registered as something difficult to teach (Figure 4.1.7). The concept of relative motion between the coil and the magnet was mentioned but not explained. Furthermore, the teacher indicated in her response to question 2.2 that teaching EMI with the aid of demonstrations, experiments, simulations and videos makes it easier to teach. However, the teacher went out of CAPS context by considering the relationship between ferromagnetic and non-ferromagnetic materials in terms of electricity generation as something difficult to teach. Furthermore, the teacher identifies the physical significance of the negative sign in Faraday’s formula as part of what is difficult to teach but gave no reference to Lenz’s law or the RHR. This pointed to her restricted understanding of Lenz’s law, although some ‘appropriate difficulty is identified and clearly formulated, knowledge about this component is not evident’, as stated in the rubric; hence, the teacher’s pPCK based on the second big idea of FL under this component was scored as ‘*adequate*’.

4.2.2.3: CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, TE1 indicates the use of demonstrations and experimental approach aided by chalkboard diagrams and simulations as some of her CTSs she would adopt to address the concept of magnetic flux. Furthermore, a lot of class activities involving calculations using formulae are suggested. Some of the questions she proposes to ask as part of her CTS involves calculations using the flux equation. However, some of the questions like defining magnetism are too elementary for the Grade 11 learners. Furthermore, she does not mention how she will approach some of the subordinate ideas like magnetic field strength and flux change, and the difference between magnetic field strength and magnetic flux. Although her response lacks some aspects of CS, ‘the overall CTS is workable and there is evidence of encouragement of learner involvement’, as stated by the rubric, hence, the teacher's pPCK based on the first big idea of MF under this component was scored as '*developing*'.

For the second big idea of FL, TE1 mentions the need to introduce the EMI concept through linking it verbally to MF. The CTS to involve asking questions related to definitions of magnetic flux and EMF, providing factors governing EMF output, stating Faraday's law and using formulae to perform numerical calculations. Figure 4.1.8 shows some of the teacher's suggested questions to be asked during the lesson.



4.2 What questions would you consider important/necessary to ask in your teaching strategies?	-Define magnetism -How do we represent magnetic field lines -Calculate using the equation $\phi = BA\cos\theta$ What would be the value of ϕ if $\theta = 0°$ or $\theta = 90°$	-Define magnetic flux -What is the difference between magnetic flux and magnetic field -Define Emf and state Faraday's law ~~of magnet that~~ . -for emf to be induced, is it coil or magnet that must move -Calculate using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ -What is the meaning of negative sign -How can emf signal be increased

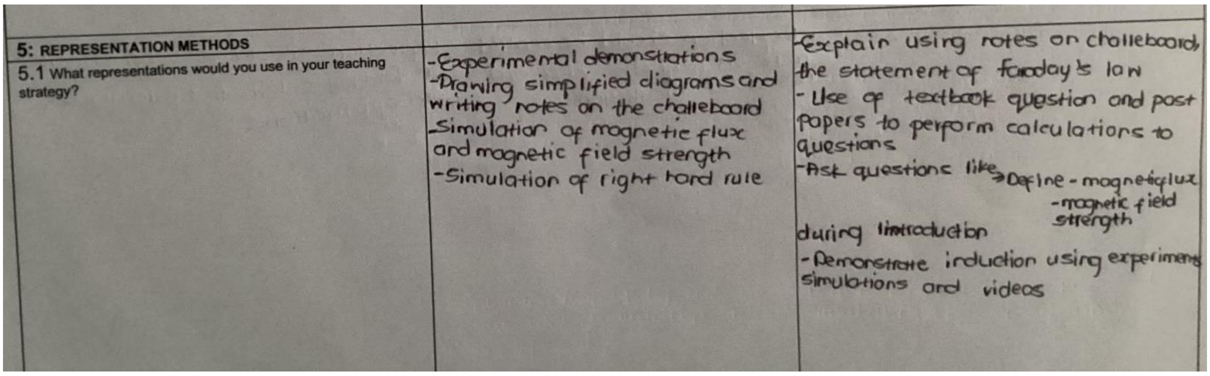
Figure 4.1.8: Snapshot of TE1's 'Conceptual teaching strategies' for MF (left) and FL (right) after the intervention workshop. Source: Researcher's own.

However, the CTS of the direction of induced current as a subordinate idea 'lacks some aspects of CS'. In this regard the teacher indicated that she would ask a question regarding the physical significance of the negative sign in Faraday's formula but did not mention questions associated with using Lenz's law and the RHR application.

Consequently, TE1's pPCK based on the second big idea FL under this component was scored as '*developing*'. This is because 'the response also lacks some aspects of CS', as stated by the rubric.

4.2.2.4: REPRESENTATIONS

TE1 opts to extensively make use of simulation videos as visual and symbolic representations to enable learners to conceptualise the big ideas of MF and FL. She prescribes the use of handouts, worksheets, simulations, demonstrations and simplified chalkboard diagrams for numerical, graphical and diagrammatic representations to enforce specific aspects of both big ideas of MF and FL as indicated in figure 4.1.9.



5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	-Experimental demonstrations -Drawing simplified diagrams and writing notes on the challeboard -Simulation of magnetic flux and magnetic field strength -Simulation of right hand rule	-Explain using notes on challeboard, the statement of Faraday's law - Use of textbook question and post papers to perform calculations to questions -Ask questions like → Define - magnetic flux - magnetic field strength during introduction - Demonstrate induction using experiments simulations and videos

Figure 4.1.9 Snapshot of representations of big ideas of MF (left) and FL (right) after the intervention workshop. Source: Researcher's own.

It is evident from her constructed CoRes based on the big ideas of MF and FL that she has knowledge about computer-integrated education (CIE) and its pedagogical implication. She portrays some understanding of modern methods of representations to enhance conceptual cognitive development in both big ideas of MF and FL. Her's pPCK based on both big ideas of MF and FL of this component was scored as '*developing*' because 'there is evidence that the suggested extensive use of representations (visual / pictorial) to enforce specific aspect(s) of concepts being developed', as described by the rubric.

4.2.3 COMPARISON OF TE1's PRE- and POST-INTERVENTION CoRes

The scores for each PCK component from tables 4.1.1 and 4.1.2 are compared in order to gain an overall impression of whether the scoring levels have improved following the intervention. Table 4.1.3 shows a summary of these scores.

Table 4.1.3 Summary of TE1's pre- and post-intervention personal PCK scores.

PCK component	**PCK SCORING LEVEL SUMMARY**															
	PRE-CoRe								**POST-CoRe**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency	x			o									x	o		
Learner understanding	x	o										o	x			
Conceptual teaching strategies	x			o									x	o		
Representations			x	o									x	o		

From table 4.1.3, the immediate observations which one would make is that the PCK scores shifted from predominantly limited (L) and adequate (A) in pre-intervention CoRe to predominantly developing (D) in the post-intervention CoRe. The post-CoRe scores highlighted in yellow shows a noticeable improvement after the intervention compared to pre-CoRe scores. This gives the general impression that the intervention had an impact on the way TE1 constructed her post-intervention CoRes. After the intervention her responses to the same CoRe prompt changed and improved while responding to the post-intervention CoRes.

The increased scores in the post-intervention CoRe may be ascribed to uncertainty about how to respond to the CoRe prompts. This was evident in the way she completed her pre-intervention CoRe compared to the post-intervention CoRe based on both the two big ideas of MF and FL (see Appendices **A1** and **C1**). Her attempt to complete the pre-intervention CoRe tool was associated with some challenges as evidenced by her partially filling the spaces (see Appendix **A1**). However, after the intervention workshop, she responded to all the post-intervention CoRe prompts (see Appendix **C1**).

TE1's reported personal PCK scores as demonstrated in her constructed post-intervention CoRes based on the big idea of FL of EMI section of Grade 11 were mostly 'developing'. The level of PCK which she demonstrated prior to the period of intervention can be considered to be at a lower level compared to her personal PCK after the intervention. Evidence extracted from Appendix **A1** clearly demonstrates the inadequate PCK level of the teacher.

To make a numerical comparison, the scores were represented on a numerical scale of 1 to 4, where 1 = limited, 2 = adequate, 3 = developing and 4 = exemplary. The scores were then added and averaged in order to compare the post-CoRe to the pre-CoRe scores. Table 4.1.4 shows the comparative PCK scores on a numerical scale.

Table 4.1.4: Summary of TE1's comparative PCK scores on a scale ranging from 1 to 4.

PCK Components	**PCK Scoring levels**					
	Pre-CoRe			**Post-CoRe**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	1	2	1.5	3	3	3.0
Learner understanding	1	1	1.0	3	2	2.5
Conceptual teaching strategies	1	2	1.5	3	3	3.0
Representations and analogies	2	2	2.0	3	3	3.0
Total (16)	5	7	6.0	12	11	11.5
Average (4)	1.4	1.6	1.5	3.0	2.6	2.8

From the weighted scores in table 4.1.4, there was a noticeable difference between pre-CoRe scores and post-CoRe scores based on the big idea of MF. The post-CoRe MF scores increased by an average of 1.6 points (from 1.4 to 3.0) after the intervention. A noticeable difference was observed between pre-CoRe scores and post-CoRe scores based on the big idea of FL. The scores based on the big idea of FL increased by an average of 1.0 points (from 1.6 to 2.6) after the intervention. Combining the two big ideas the overall average score increased by 1.3 points (from 1.5 for pre-CoRe to 2.8 for post-CoRe). This is evidence that the intervention had an impact in the way she constructed her CoRes based on EMI prior to teaching it.

4.2.4 VIDEO-RECORDED LESSON OBSERVATIONS: THE CASE OF TE1.

The transcript of the video-recorded lesson is available in Appendix D1. Four sections were identified from her video-recorded lesson: Teacher TE1 taught both big ideas, (ie, MF and FL) in just one lesson. The entire lesson lasted for 62 minutes and 6 seconds.

<u>Section 1</u>: Introduction revision of knowledge based on the previous lesson. [5 min 53 sec]

In her introductory phase, she started off by recapping the section which she had just completed based on the magnetic effect of a coil carrying current. Some of the questions she asked her learners were based on the application of the RHR to the straight conductor and solenoid carrying current. This was a revision of the magnetic effect of current. Next, she introduced the concept of 'induction' by explaining how Faraday reasoned that if electricity creates magnetism, then magnetism should create electricity, so there should be an 'electric effect of magnetism'.

<u>Section 2</u>: Teaching the first big idea of MF followed by a short classwork assessment [16 min 13 sec]

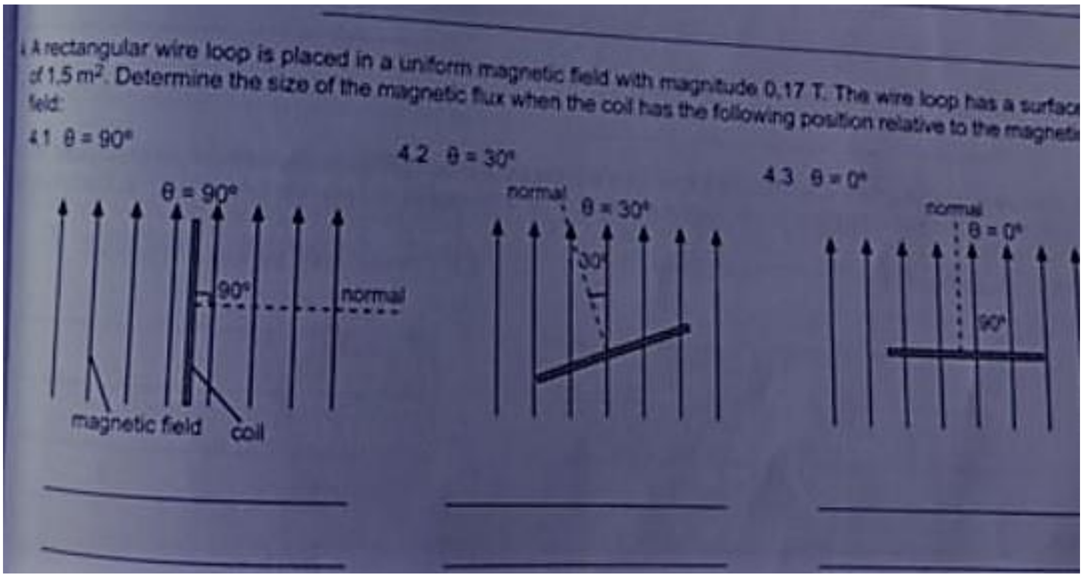
Teacher TE1 did not indicate the relevance of the loop; this is the conductor in which current would be induced. Instead, she proceeded to introduce the concept of magnetic flux to her learners by saying:

> **TE1**: *Now, we want to discuss about magnetic flux before we finally present Faraday's law of EMI. Magnetic flux is a product of the component of magnetic field strength and cross-sectional area of the loop.*

She then provided the mathematical formulation of magnetic flux and further explained the physical meaning of each of the symbols. She went further to explain how to visualise magnetic flux:

> **TE1:** *Magnetic flux in other words simply brings into imaginary perspective, the flow of field lines or field flow. Magnetic flux is measured in webers (Wb).*

In her representation of the first big idea of MF, she only made use of diagrams in the handouts and, chalkboard for some illustrations and explanations. The teacher solved some problems from the worksheets and used them as examples to aid explanations. She then gave her learners three questions from the worksheets based on the calculation of magnetic flux as part of her CTS. Figure 4.1.10 is an example of a question based on magnetic flux which learners answered as individuals.



4 A rectangular wire loop is placed in a uniform magnetic field with magnitude 0,17 T. The wire loop has a surfac of 1,5 m^2. Determine the size of the magnetic flux when the coil has the following position relative to the magneti field:

4.1 $\theta = 90°$

4.2 $\theta = 30°$

4.3 $\theta = 0°$

Figure 4.1.10: Snapshot of question from learners' worksheet based on magnetic flux. Source: Researcher's own.

While the learners were busy responding to the questions in their workbooks, the teacher went around checking and monitoring progress as well as assisting individual learners.

<u>Section 3:</u> Teaching the second big idea based on Faraday's law and EMI followed by a short practice exercise [34 min 48 sec]

The teacher went on to verbally introduce Faraday's law of EMI while linking it with the first big idea of MF. She presented the mathematical formulation of Faraday's law on the chalkboard and went further to explain the physical significance of each symbol.

As part of her CTS, she worked two examples based on Faraday's law numerical calculations before giving the learners some questions to attempt as individuals in their classwork books.

In her EMI representation, she made use of the chalk board as well as a video of a simulation from her personal laptop. Some interesting observations such as the motion of the magnet into and out of the coil, were made related to EMI and the simulation video brought a lot of learner excitement. The following is an extract from the lesson related to one of the simulation videos:

> **TE1:** *Now what about when the magnet is held stationary inside the coil, just watch this part now. What happens and why?*

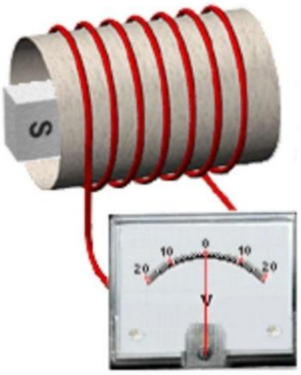


Figure 4.1.11: Screenshot of simulation showing magnet held stationary inside the coil

> **Learner 7:** *The pointer of the galvanometer reads zero and no emf is induced inside the coil of wire. I think it is because there is no motion.*
>
> **TE1***: You have said it well my boy. Which means that our emf is induced only when the magnet makes a movement into or out of the coil.*

The video presentation strategy and questioning technique to teach the required concepts of the second big idea of FL was successful and encouraged learner involvement. However, the teacher did not take this opportunity to explain the concept of relative motion to her learners. She referred to movement of the magnet, not the possible movement of the coil. This pointed to a possible filter between the collective PCK about EMI teaching and her pPCk and ePCK that suggest that the teacher has restricted understanding of ‘relative motion’. Alternatively, she may have forgotten to mention possible movement of the magnet. She did not even relate the motion to flux change. Furthermore, she did not make use of any real apparatus to demonstrate or to let the learners experiment themselves. Also, she did not teach them about the direction of the induced current. However, the principle of induced current opposing the cause of induction is included in the curriculum, even though the curriculum does not explicitly refer to “Lenz’s Law”. She actually said during the lesson that Lenz’s law is not in the CAPS syllabus. The following is the teacher’s response when one of her learners asked the physical significance of the negative sign in Faraday’s EMI formula:

> **TE1**: *That’s a very good question my boy. But for now, don’t bother yourself about the physical significance of the negative sign. The negative sign has to do with something associated with what we call Lenz’s law and it’s not in your syllabus. We cannot waste our time on something that will never be examined.*

That means she did not realise that determining the direction of the induced current actually uses Lenz's Law and the application of the RHR. This leaves the question as to why she emphasised the RHR during the introduction. This would impact her score for CS based on the second big idea.

Section 4: Concluding the lesson [5 min 12 sec].

TE1 concluded her lesson by providing a brief summary of the entire lesson. She mentioned the application of EMI in electric generators.

In her introduction, she started off by recapping the physics of the RHR which was dealt with in the previous lesson. However, she did not explain during the lesson that the RHR is applied to the induced current as deduced by using Lenz's law. She then introduced the first big idea of MF and later linked it to the second big idea of FL. A successful video of a simulation was presented based more specifically on the second big idea of FL. The lesson attracted the learners' attention and enthusiasm more specifically during simulations. The conceptual teaching strategy based on the second big idea of FL encouraged a lot of learner involvement. However, the conceptual scaffolding from magnetic flux to EMI was not clear. It was mostly formulaic and algebraic. She did not try to help her learners visualise changing flux as an agent bringing about current in the loop.

4.2.5 TEACHER TE1'S VSRI RESPONSES.

The transcript of the VSRI session is available in Appendix E1. The VSRI session was held at TE1's school a day after conducting the video-recorded lesson observation. The VSRI provided more insight into how the teacher enacted her PCK. During the VSRI session she acknowledged the importance of reflecting on the lesson especially by making use of evidence based on video recordings.

Researcher: **What is your personal impression regarding video-recorded lesson observations?**

The teacher indicated that a lot needed to be done under the PCK component of representations:

Researcher: **Were you satisfied with your EMI representation method?**

> **TE1**: *I am also thinking of exploring the use of pre-selected YouTube videos as a teaching method next time to represent EMI.*

She seemed to be satisfied with her presentation of FL, even though it lacked conceptual scaffolding

> **TE1**: *I started off by linking the lesson on EMI and magnetic flux to the previous lesson which was based on magnetic field around a coil-carrying current. I then went on to introduce the concept of electromagnetic induction and Faraday's law. I was also able to demonstrate Faraday's law of EMI via simulation methods*.

However, the VSRI session confirmed three gaps which were noticed in her lesson presentation. These gaps compromised the level of development of her PCK. During the VSRI session, three challenges related to content and curriculum presentation were noticed. It was during the VSRI session that the teacher first acknowledged her lack of understanding of certain concepts as discussed below.

Firstly, in the video play back (VPB) of the lesson, the teacher was quoted saying:

> **VPB-1**"……*Which means that our emf is induced only when the magnet makes a movement into or out of the coil"*

During the VSRI session when asked about relative motion with reference to EMI, the teacher realised that she made a mistake:

> **TE1**: *Mmmmmmh of course! Or is it not correct to say that only the coil is stationary and it's the magnet which should move into or out of the coil? I guess you are not trying to suggest for me relative motion of coil and magnet. Ohh…! It's true that is the meaning of relative motion. I messed up. I will have to address that again.*

The teacher was responding to a question about whether it is only the magnet that makes movement while the coil is stationary. She taught her learners that EMF would be induced if only the magnet makes a movement. The actual meaning of relative motion became clearer to her during the VSRI session through reflection and she promised to re-address the concept with her learners.

Secondly, she realised her lack of understanding of the difference between magnetic field strength and magnetic flux. In another instance during the VPB, the teacher was heard saying the following to her learners:

> **VPB-2** "………*..'B' represents magnetic field strength measured in tesla (T) and, mean almost the same as magnetic flux. …..*"

During the VSRI session, the teacher remarked:

> **TE1:** *That is how I always perceive it. I guess I must change the perception I have for magnetic flux and magnetic field strength. I also must revisit my archives that I am using as my Physics resource base.*

She however indicated that she needed to revisit her literature in order to revive her memory system and develop her content knowledge in line with electromagnetism.

Thirdly, she revealed restricted understanding of Lenz’s law and its role in the Physical Sciences curriculum. This was clear from yet another VPB where the teacher was heard responding to one of her learners who had asked the physical significance of the negative sign in Faraday’s formula:

> **VPB-3** “……*something associated with what we call Lenz’s law and it’s not in your syllabus. We cannot waste our time on something that will never be examined.”*

The teacher strongly defended her actions during the VSRI session and justified her actions by saying:

> **TE1**: *Even though the learner might have asked a relevant question, but there was no need for me to entertain the question in the presence of other learners. The explanation might see me dragging the lesson and eventually being left behind the pacesetter. That is why I requested the learner to see me as an individual for further clarity on Lenz’s law.*

Her reaction suggested that she did not understand that the application of Lenz’s law is actually implicit in the curriculum.

4.2.6 SEMI-STRUCTURED INTERVIEW RESPONSES

The transcript of the semi-structured interview (SSI) session is available in Appendix F1. An SSI session was conveniently carried out after school hours at TE1’s workstation and in the comfort of her office, to avoid disrupting her lessons and other school programmes. The SSI session was carried out three days after the video-recorded EMI lesson observation. The entire SSI session lasted for approximately twenty-five minutes and TE1 responded to all the questions asked during the interview session. The entire SSI session was audio-recorded with the teacher’s permission.

Some of the teacher’s responses during the SSI session are similar to those given during the VSRI session. However, a lot more was discussed during the SSI session. For instance, it was during the SSI session that the teacher acknowledged her own misunderstanding about the application of the RHR. When a question pertaining the stance of the CAPS syllabus on direction of induced current was asked to the teacher,

> **Researcher:** *Did you go through the CAPS document to check and see what you are expected to teach and what learners are expected to know in the section of electromagnetic induction?*

she responded:

> *Yes, its mentioned that learners are expected to know the direction of induced current. Oh!, that is Lenz's law. But they supposed to straight away talk about Lenz's law instead of beating about the bush. I guess I should go through it again to see since I might have missed a lot of other things.*

Clearly the researcher's question during the SSI session guided the teacher to understand the connection between the direction of the induced current and Lenz's law. Then she realised that the curriculum is not very clear, 'beating about the bush' instead of mentioning it explicitly.

When asked what she had learnt from participating in the study and what she would intend to work on to improve her professional growth, she said the following:

> *Nothing more. With my CoRe tool and video recorded lesson what else can I ask for? This intervention actually assisted me in identifying some misconception which I was having in this section of EMI and Faraday's law. For instance, the issue of relative motion between coil and magnet, the issue of the difference between magnetic flux and magnetic field and obviously Lenz's law.*

The teacher indicated that she previously did not give maximum attention to EMI as she sometimes used to treat the section just for the sake of compliance and content coverage. She admitted that both MF and FL required thorough preparation. When asked about the effectiveness of CoRes in conjunction with a video-recorded lesson, she appreciated the effectiveness of CoRes during lesson preparation and video recording the lesson. She said the following as part of her future approach to EMI:

> *…..use my lesson preparation in conjunction with my content representation tool. I will video record any lesson with abstract concepts such as electromagnetism. From video playback I will be able to reflect on my lesson and compare what I had planned with how I actually did it……….*

Furthermore, she expressed her dissatisfaction with her use of representations and went further to explain that she had limited options available while teaching the big ideas of MF and FL to her learners. She went further to suggest the use of real experiments instead of simulations as a representation and part of the CTS:

> *If a school's laboratory system is adequately resourced; I would advocate for the experimental approach because hands on experience with apparatus will enable learners to concretise concepts….*

The teacher preferred an experimental CTS approach but could not undertake it in her lesson due to inadequate laboratory resources. In her opinion, the use of simulations was to be adopted under circumstances where the school might be equipped with adequate CIE resources.

4.2.7 SCORING ENACTED PCK for TE1

In this section, the researcher links what transpired during the video-recorded lesson observation with the teacher’s VSRI and SSI aftermath responses to evaluate her enacted PCK. The scores were assigned to each of the specific PCK components based on the video recordings of the lesson observations as well as teacher’s VSRI and SSI responses. Table 4.1.5 presents these scores. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

This discussion focuses on interesting aspects of TE1’s video-recorded EMI pedagogical enactment in view of the selected key ideas in her CoRes.

Table 4.1.5: Scores of TE1 based on enacted PCK

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency			x	o				
2	Learner understanding			x	o				
3	Conceptual teaching strategies				o	x			
4	Representations			x			o		

4.2.7.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, evidence gathered from the video-recorded lesson shows that the teacher started with an introduction which involved recapping concepts from the previous lesson. She then went on to introduce the big idea of MF while making use of verbal explanations being aided by illustrations of chalkboard and worksheets diagrams. The teacher went further to present the formula used for the calculations of flux. Two examples based on calculations of flux were then given on the chalkboard during a teacher-led discussion. The learners were then tasked to respond to some worksheet-selected questions in their classwork books. She was then observed moving around monitoring progress and attending to individual concerns.

However, evidence gathered from the video-recorded lesson indicated that learners were taught that there was close similarity between magnetic flux and magnetic field. Sound content knowledge is not evident. She knew the equation but did not understand that the two symbols in the equation (φ and B) do not refer to the same concept. She expressed it to the learners as if it was one and the same thing. Her ePCK for this CS component based on the first big idea of MF is scored as '*adequate*' because 'Knowledge of curriculum was not evident' and the identified 'subordinate ideas were limited to being aware of the definitions, equations or terms' as stated by the rubric.

For the second big idea of FL, the teacher introduced the lesson based on EMI by reminding learners on the importance of the RHR for the solenoid and for the straight conductor. Next, the teacher introduced the concept of EMI by explaining Faraday's argument that if electricity can create magnetism, then magnetism should create electricity. During the lesson she said:

> *"The discovery of EMI has made it possible for us to generate electricity. Faraday was a great scientist, isn't it?......."*

During the VSRI session when TE1 was requested to provide an overview of her lesson based on video playback, she indicated that she was satisfied with her lesson, clearly unaware that her presentation did not promote conceptual understanding:

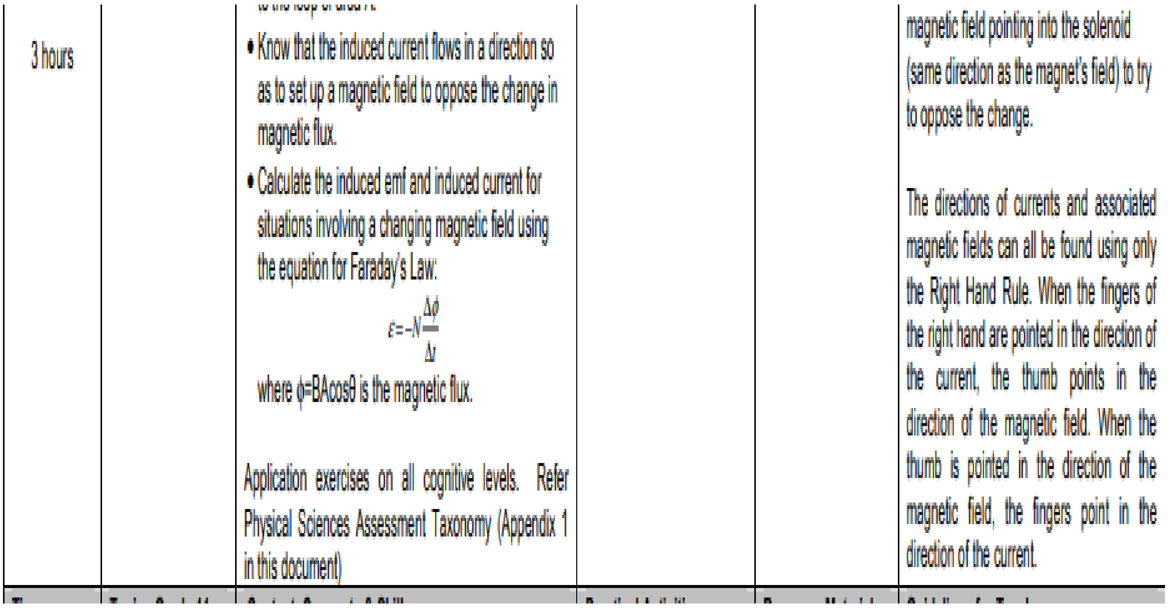
> *I think my introduction is ok because I started off by linking the lesson on EMI and magnetic flux to the previous lesson which was based on magnetic field around a coil-carrying current. I then went on to introduce the concept of electromagnetic induction and Faraday's law.*

During the lesson she indeed gave a good introduction. She showed awareness of the concept of EMI by often referring to pre-concepts as well as forthcoming concepts. Evidence gathered from the video-recorded lesson observations indicate that there is conceptual sequencing and understanding of scaffolding of subordinate ideas required when teaching EMI. Furthermore, the RHR, magnetic flux and general principles of magnetism were utilised as the major pre-concepts needed for learners to understand EMI. However, her presentation of relative motion as well as the direction of induced current was inadequate.

Evidence gathered from the video-recorded lesson indicated that relative motion was taken to imply movement of the magnet into and out of the coil. This perception could have a negative impact on the learner's conceptualisation of Faraday's law. Furthermore, the negative sign presented in the mathematical formulation of Faraday's law was overlooked, and a necessary and satisfactory explanation was not presented to the class. During the VSRI session, the teacher justified herself by saying:

> "*……something associated with what we call Lenz's law and it's not in your syllabus. We cannot waste our time on something that will never be examined.*"

The teacher seemed to be relieved about the CAPS syllabus not explicitly referring to Lenz's law despite it being essential when teaching about EMI and Faraday's law. This gave her an excuse of omitting the minus sign in the equation. Clearly, the teacher lacked comprehensive interpretation of the curriculum or might not have thoroughly gone through page 67 of the CAPS document (DBE, 2011, p.67). Figure 4.1.12 is an extract from the CAPS document.



3 hours		• 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 $\phi=BA\cos\theta$ is the magnetic flux. Application exercises on all cognitive levels. Refer Physical Sciences Assessment Taxonomy (Appendix 1 in this document)			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 4.1.12: Extract from the CAPS document. Source: DBE (2011, p.67).

The CAPS document clearly stipulates the examinable content and, in this case, learners are expected to "Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux" (see Figure 4.1.12). This is actually Lenz's Law.

This pointed to inadequate content knowledge as a possible filter that negatively impacts on the teacher's knowledge of CS. She justified her avoiding the topic by suggesting that it is not examined as indicated in the quote above.

Furthermore, she did not make use of the RHR while teaching FL although in her introduction she treated it as a pre-concept. Although the teacher made her intentions clearly known to the learners, some important concepts such as the direction of induced current and relevance of the RHR together and the application of Lenz's law were omitted in her lesson. This was a shortcoming in her lesson since she did not cover the entire curriculum expectations in line with Grade 11 electromagnetism. This further indicates a gap in her knowledge which impacted her score for CS, hence TE1's ePCK for this component based on the second big idea of FL was scored as '*adequate*' because 'the response also lacks some aspects of CS and the correctly identified subordinate ideas were limited to being aware of the definitions, equations or terms', as stated by the rubric.

4.2.7.2: KNOWLEDGE OF LEARNER UNDERSTANDING?

During the SSI session TE1 referred to general challenges:

> *EMI and Faraday's law are higher order concepts which are difficult for learners to understand such concepts. Therefore, it is imperative that experimental demonstrations or simulations be done while teaching them.*

Her decision to use simulations during the lesson was to make it easier for learners to understand. She cited lack of suitable laboratory equipment in school without which concretisation of EMI concepts by learners cannot be practically enhanced. During the VSRI and SSI sessions while responding to a question based on challenges associated with teaching EMI, TE1 mentioned that learners have misconceptions:

> *EMI is a high order concept with strong mathematical background. Another point is that the imaginations to be taken into considerations when it comes to generation of an emf are far beyond the reach of most of our high school learners. That's why there are also a lot of alternative conceptions by learners and even some teachers.*

However, during teaching, she paid no attention to some well-known challenges for both big ideas. For the concept of MF, she did not make a clear distinction between the meanings of a magnetic field and magnetic flux.

For FL she did not point out that all motion is relative. If learners do not understand the concept of relative motion, it would obstruct their understanding that induction depends on relative motion between the coil and the magnet. She only referred to the motion of the magnet.

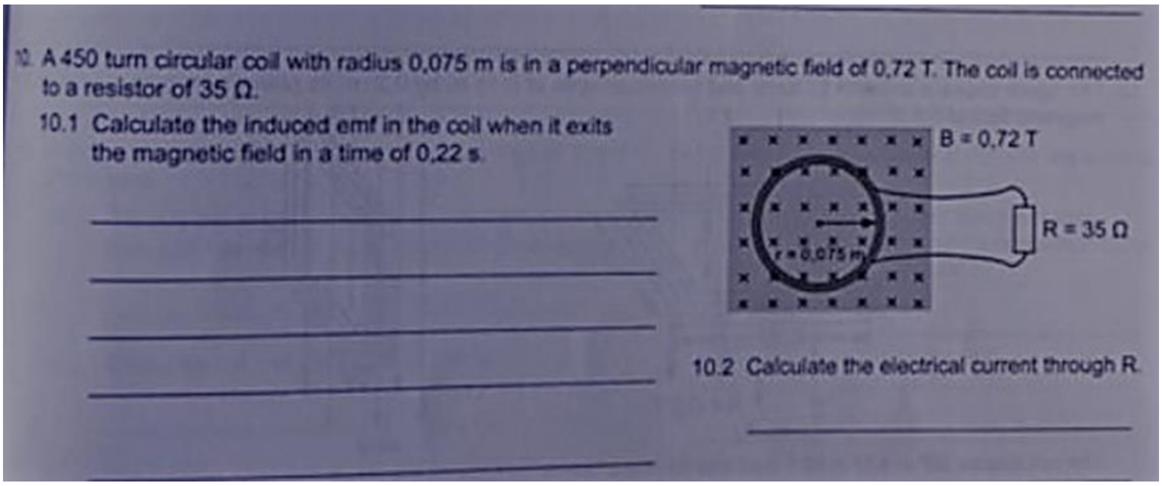
TE1 omitted the interrelatedness between Lenz's law and the RHR to predict the direction of induced current. The teacher's ePCK for both MF and FL was therefore scored as '*adequate*' because 'an appropriate difficulty related to one of the main ideas is identified and clearly formulated' as stated by the rubric.

4.2.7.3: CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, TE1 verbally explained the concept of magnetic flux with the aid of chalkboard diagrams and other illustrative examples from the worksheets. She presented the flux formula on the chalkboard and explained the physical meaning of each symbol. However magnetic field strength and magnetic flux were not clearly distinguished. This left her learners with the impression that flux and field strength are one and same thing. Furthermore, the questions asked during presentation on flux did not provoke higher-order thinking skills. Instead, the questions that trigger learners' higher-order thinking were only presented during an assessment based on the first big idea of MF.

Some of her questions presented were very difficult such that she would answer her own questions after the learners' few attempts. Her questions were rarely rephrased. At other times, her questions were simple, eliciting a chorus response from her learners. The teacher's ePCK based on the first big idea of MF of this component was scored as '*developing*' because her 'overall CTS was workable' and, 'there was evidence of encouragement of learner involvement with provision of supporting explanatory notes' as stated by the rubric.

For the second big idea of FL, the teacher presented a video of simulation as part of her CTS. Furthermore, she used the representations in combination with direct instructions. The use of a video of simulation in CTS to teach EMI and Faraday's law triggered a lot of learners' attention, and involvement. The teacher used the video of simulation to further explain how EMF was induced in accordance with Faraday's law. She guided her learners through the process of observation without directly telling them what they were supposed to see during EMI simulation presentation. However, she did not explain to the learners the physical application of the RHR in predicting the direction of the induced current. She did not take this opportunity to explain Lenz's law and physical significance of the negative sign in Faraday's formula. Furthermore, she omitted emphasis on relative motion. In fact, she left her learners with the impression that EMF was induced only if the magnet is moving into and out of the coil. Some of the questions which she asked as CTS during EMI simulations presentation did not require higher-order thinking. However, the teacher presented some questions that provoked her learners' higher-order thinking skills in a classwork assessment activity (see figure 4.1.13).



10. A 450 turn circular coil with radius 0,075 m is in a perpendicular magnetic field of 0,72 T. The coil is connected to a resistor of 35 Ω.

10.1 Calculate the induced emf in the coil when it exits the magnetic field in a time of 0,22 s.

10.2 Calculate the electrical current through R.

Figure 4.1.13: Snapshot of question from learners' worksheet based on FL. Source: Researcher's own.

The teacher's ePCK based on the second big idea of FL under this component was scored as '*adequate*' because 'the response lacks aspects of curriculum saliency', as stated by the rubric.

4.2.7.4: REPRESENTATIONS

For the first big idea of MF, the teacher made extensive use of verbal explanations aided by some chalkboard diagrams to reinforce learner understanding of the magnetic flux. Apart from that, the teacher made no attempt to demonstrate or simulate magnetic flux. She later remarked during the SSI session that she had limited options for representation of the first big idea of MF. The teacher's ePCK based on the first big idea of MF in this component was scored as '*adequate*' because 'the selection of representations (visual or symbolic) was insufficient ', as stated by the rubric.

For the second big idea of FL, TE1 made use of video of simulations in addition to verbal explanations and chalkboard diagrams to represent Faraday's law. While presenting simulations to illustrate EMI, many learners were excited and even the level of participation was higher. When asked about why she opted to integrate information and communication technology (ICT) as one of her CTS methods, TE1 justified her videos of simulation approach during the VSRI session as a method that does much to motivate and assist the learners to conceptualise the second big idea of FL. During the VSRI session she said:

> *I wanted them to at least be exposed to the correct physics of how an emf is induced in accordance with Faraday's law.*

In her lesson, chalkboard diagrams and the associated use of video of simulations were sequentially executed in an exemplary manner. Figure 4.1.14 is a screenshot of the simulations showing a deflection on the galvanometer when a permanent bar magnet moves relatively quickly into the coil.

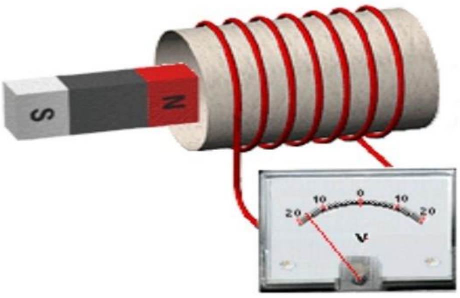


Figure 4.1.14: Screenshot of simulation showing a deflection on the galvanometer during a fast push of magnet into the coil. Source: Researcher’s own.

While TE1 could have adopted the direct experimental method as a representational strategy, she justified herself during SSI by citing the lack of adequate laboratory equipment as her main reason to opt for video of simulations. She further remarked during the VSRI session that the use of an experimental approach as a representational strategy would possibly not be effective as it required amongst other factors, the use of strong magnets to achieve some deflections of the galvanometer.

However, while the use of video of simulations by TE1 might have been a wise idea, the teacher did not show to her learners that the current reverses when pulling out the magnet from the coil. Furthermore, visual images from her personal laptop were not clearly observable by the learners situated at the back of the classroom. Under normal circumstances she could have called her learners to gather around her table or alternatively made use of a projector to show the simulations. She argued during VSRI that in the era of COVID-19 strict health protocols which include maintaining a physical distance of approximately 1.5m were to be adhered to. She also indicated during VSRI that:

> *the lesson could have been conducted in the computer centre with an overhead projector, but the centre was under full utilisation by computer application & technology (CAT) learners.*

The teacher’s ePCK based on second big idea of FL in this component was scored as ‘*developing*’ because ‘an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts was presented’ as stated by the rubric.

4.2.8 COMPARISON OF TE1’s ENACTED PCK with her POST-INTERVENTION CoRes

Table 4.1.6 shows a summary comparing the post-intervention and enacted PCK scores per PCK level.

Table 4.1.6: Comparison of TE1’s post intervention and enacted PCK scores

PCK COMPONENTS	PCK SCORING LEVEL SUMMARY															
	POST								ENACTED							
	L		A		D		E		L		A		D		E	
	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL
Curricular Saliency					x	o					x	o				
Learner understanding				o	x						x	o				
Learner Prior Knowledge				o	x								x	o		
Conceptual teaching strategies					x	o						o	x			
Representations					x	o					x			o		

From Table 4.1.6, the following observations were made with regard to post-CoRe scores compared to enacted PCK scores:

The scores highlighted in green show a decrease in enacted scores compared to post-CoRe scores. The green highlighted scores provide evidence that the teacher’s personal PCK was not fully enacted during teaching. Evidence gathered from the video-recorded lesson observations, VSRI session and SSI indicate that TE1’s enacted PCK especially in the component of curricular saliency were weaker than in the post-CoRe. This might be attributed to some aspects of the curriculum that were not convincingly covered due to teacher’s poor conceptual understanding of how the RHR and Lenz’s law are applied in EMI, hence, the immediate observations which one would make is that the PCK scores for enactment are noticeably lower than scores in the post-CoRes, shifting from predominantly developing (D) in post-intervention CoRe to predominantly adequate (A) during the enactment of PCK.

During her PCK enactment, she revealed her awareness of the magnetic effect of a coil carrying current as the necessary prior knowledge needed by learners before exposing them to the concepts of magnetic flux and EMI. However, she was not able to clarify the difference between magnetic flux and magnetic field strength needed when teaching the concept of EMI. When asked to comment about challenges faced during the teaching of EMI, TE1 acknowledged during the SSI session, that her own major misconceptions and lack of knowledge based on the first big idea of MF, rate of change of magnetic flux, relative motion between coil and magnetic flux in Faraday’s law, and physical significance of the negative sign depicted in the mathematical formulation of Faraday’s law:

> *This intervention actually assisted me in identifying some misconception which I was having in this section of EMI and Faraday's law. For instance, the issue of relative motion between coil and magnet, the issue of the difference between magnetic flux and magnetic field and obviously Lenz's law.*

The teacher acknowledged during the VSRI sessions that her own misconceptions would seriously thwart the intended goals of a successful lesson-based learning of new concepts.

> *I guess you are not trying to suggest for me relative motion of coil and magnet. Ohh! It's true that is the meaning of relative motion. I messed up. I will have to address that again*

The video-recorded lesson observations highlighted a fruitful demonstration of the second big idea of FL in which the teacher made use of simulations as suggested in her post-CoRe.

However, for the concept of 'relative motion' enshrined in Faraday's statement of the law and for the negative sign presented in the mathematical formulation of Faraday's law, TE1 showed poorer PCK. She acknowledged during the VSRI session that she overlooked the fact that her simulation 'representation' can demonstrate relative motion and Lenz's law. While constructing her CoRes based on EMI in terms of curricular saliency, she mentioned that she would sequence her lesson by first discussing the magnetic flux before introducing Faraday's principle. She however clarified this sequence, stating that it would assist the learners in comprehending the major ideas underpinning the concept of EMI.

The general impression is that there is convincing evidence (highlighted in green) suggesting that the teacher's personal PCK was not fully enacted during teaching.

To make a numerical comparison, the scores were represented on a numerical scale of 1 to 4, where 1 = limited, 2 = adequate, 3 = developing and 4 = exemplary. The scores were then added and averaged in order to compare the post-CoRe to the ePCK scores. Table 4.1.7 shows the comparative PCK scores on a numerical scale.

Table 4.1.7: Summary of TE1's comparative PCK scores in the post-CoRes and in enactment on a scale ranging from 1 to 4.

PCK Components	**PCK Scoring Levels**					
	Post-CoRe			**Enacted PCK**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	3	3	3.0	2	2	2.0
Learner understanding	3	2	2.5	2	2	2.0
Conceptual teaching strategies	3	3	3.0	3	2	2.5
Representations	3	3	3.0	2	3	2.5
Total (16)	12	11	11.5	9	9	9.0
Average (4)	3.0	2.6	2.8	2.4	2.4	2.4

From the numerical scores in Table 4.1.7, there was a noticeable difference between post-CoRe scores and ePCK scores based on the big idea of MF. The scores based on the first big idea of MF decreased by an average of 0.6 points (from a score of 3.0 to 2.4) for PCK enactment. However, there was a noticeable difference between post-CoRe scores and ePCK scores that was observed based on the second big idea of FL. The enacted PCK scores based on the big idea of FL decreased by an average of 0.2 points (from a score of 2.6 to 2.4) for PCK enactment. Combining the two big ideas, the overall average score decreased by an average of 0.4 points (from 2.8 for post-CoRe to 2.4) for ePCK. This is evidence that the teacher's personal PCK was ineffectively enacted during teaching.

4.3 THE CASE OF TEACHER TE2

Teacher TE2 is an experienced male in his early 50s. He holds a B Ed degree majoring in Physical Sciences. He also holds a master's degree in Physics education. He joined the Mpumalanga Education Department as a Grade 10 to 12 Physical Sciences teacher in 2008.

TE2 is one of the permanent employees at his current secondary school where English is the language of instruction across the curriculum. The school is in a rural set-up and enrols from Grade 8 to 12. At the time when this study was conducted, the school had an overall enrolment of 751 learners, and TE2 was involved in teaching two Grade 11 Physical Sciences classes each with 51 learners. He has been the only one available and assigned to teach Physical Sciences at his school.

The teacher mentioned during my first visit to his school that he would need at least four periods to complete the Grade 11 topic of electromagnetism. For the purposes of this study, we agreed that one of his Grade 11 lessons based on EMI would be video-recorded. He presented the entire topic during this session, lasting about 70 minutes. The findings based on how he constructed his pre-CoRes, post-CoRes and, later enacted his PCK based on Grade 11 EMI are detailed in the following sub-sections from 4.3.1 to 4.3.8.

4.3.1 PRE-INTERVENTION CoRes

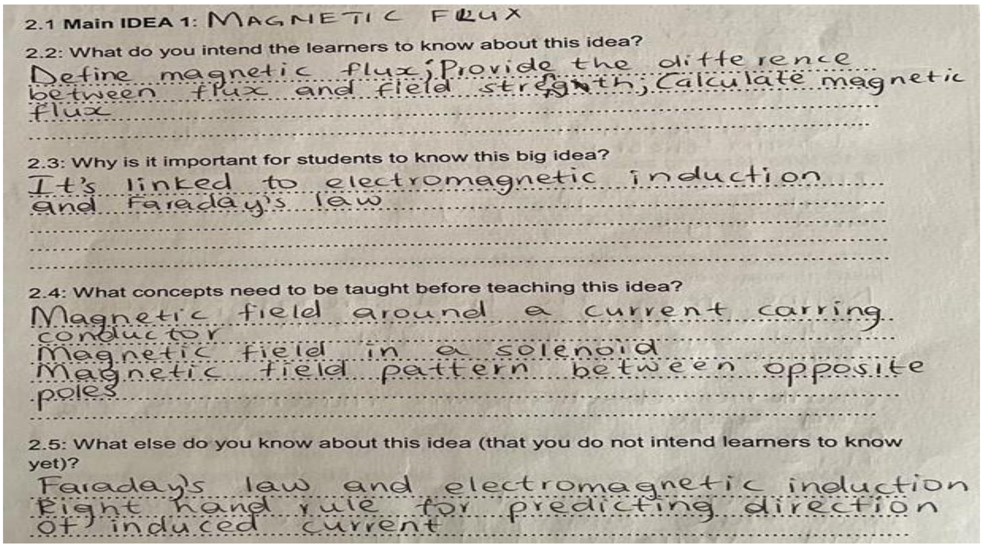
TE2 responded to all the sections of the pre-intervention CoRe. Most of his responses can be attributed to his experience as a Grade 11 Physical Sciences teacher (see Appendix **A2**). Table 4.2.1 shows the result of the scores obtained after a thorough scrutiny of responses. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.2.1: Scores of TE2 based on pre-intervention CoRes in the big ideas of magnetic flux (MF) and Faraday's law (FL)

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency			x	o				
2	Learner understanding			x	o				
3	Conceptual teaching strategies					x	o		
4	Representations					x	o		

4.3.1.1 KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, most of his responses to questions 2.2 to 2.5 shown in figure 4.2.1 demonstrated his experience in how he teaches Grade 11 EMI. While responding to question 2.2, the teacher indicated that he intends his learners to know the definition of magnetic flux as well as the principal differences between flux and field strength.



2.1 Main IDEA 1: MAGNETIC FLUX

2.2: What do you intend the learners to know about this idea?
Define magnetic flux; Provide the difference between flux and field strength, Calculate magnetic flux

2.3: Why is it important for students to know this big idea?
It's linked to electromagnetic induction and Faraday's law

2.4: What concepts need to be taught before teaching this idea?
Magnetic field around a current carring conductor
Magnetic field in a solenoid
Magnetic field pattern between opposite poles

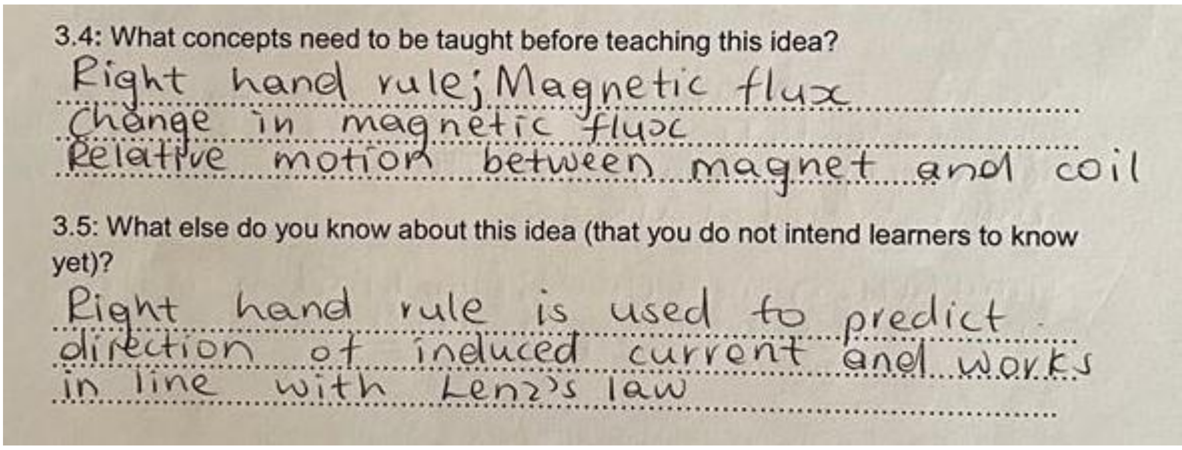
2.5: What else do you know about this idea (that you do not intend learners to know yet)?
Faraday's law and electromagnetic induction
Right hand rule for predicting direction of induced current

Figure 4.2.1 Snapshot of TE2's pre-CoRe responses to CS based on the big idea of MF. Source: Researcher's own.

He went further to outline in question 2.3 that the concept of Faraday's law which he intended to teach after MF relied on the learners' prior understanding of magnetic flux. The teacher indicated that it was imperative that the learners be exposed to knowledge of the existence of a magnetic field around a coil-carrying current and through the solenoid. Representing the magnetic field patterns between opposite poles of magnets was also indicated as the learners' knowledge base before being taught the MF.

However, it was unclear why the teacher mentioned the RHR while responding to question 2.5 since he had already taught it to his learners. It is possible that he was referring to the RHR for induction, referred to as Fleming's RHR, which is only taught in Grade 12 for generators.

For the second big idea of FL, the teacher indicated in his response to question 3.2 that he wanted his learners to have knowledge based on Faraday's law and Lenz's law. The teacher further indicated while responding to question 3.4 that this was imperative for the learners to be exposed to the RHR, flux and change in flux as pre-concepts before teaching them Faraday's law as shown in figure 4.2.2.



3.4: What concepts need to be taught before teaching this idea?

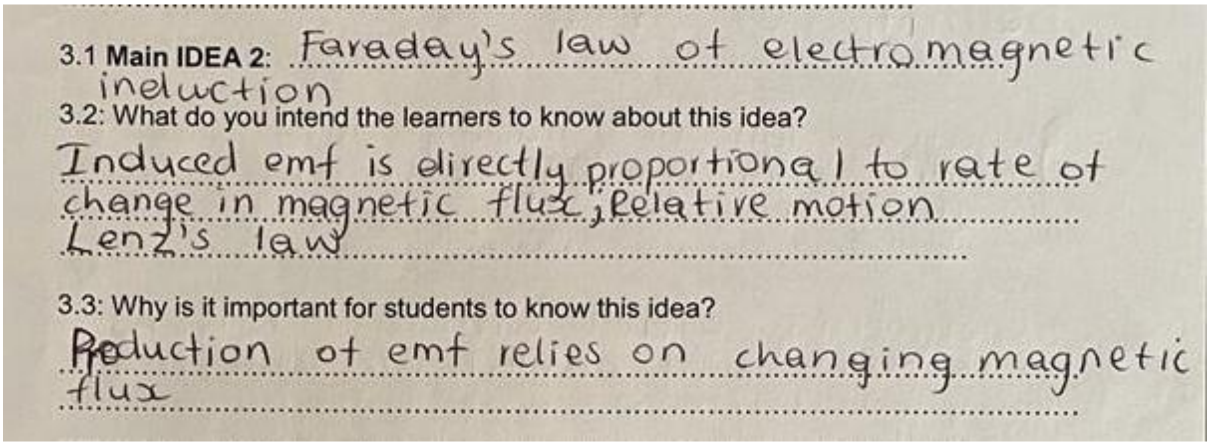
Right hand rule; Magnetic flux
Change in magnetic flux
Relative motion between magnet and coil

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

Right hand rule is used to predict
direction of induced current and works
in line with Lenz's law

Figure 4.2.2: Snapshot of TE2's pre-CoRe responses to CS based on the big idea of FL. Source: Researcher's own.

The teacher's response to question 3.5 shown in figure 4.2.2, further demonstrated the importance of the RHR in predicting the direction of the induced current in line with Lenz's law. However, the teacher's response to question 3.3 was not clear or was rather incomplete. In other words, the way he responded to question 3.2 shown in figure 4.2.3 does not link well with his response to question 3.3.



3.1 **Main IDEA 2**: Faraday's law of electromagnetic
induction

3.2: What do you intend the learners to know about this idea?

Induced emf is directly proportional to rate of
change in magnetic flux; Relative motion
Lenz's law

3.3: Why is it important for students to know this idea?

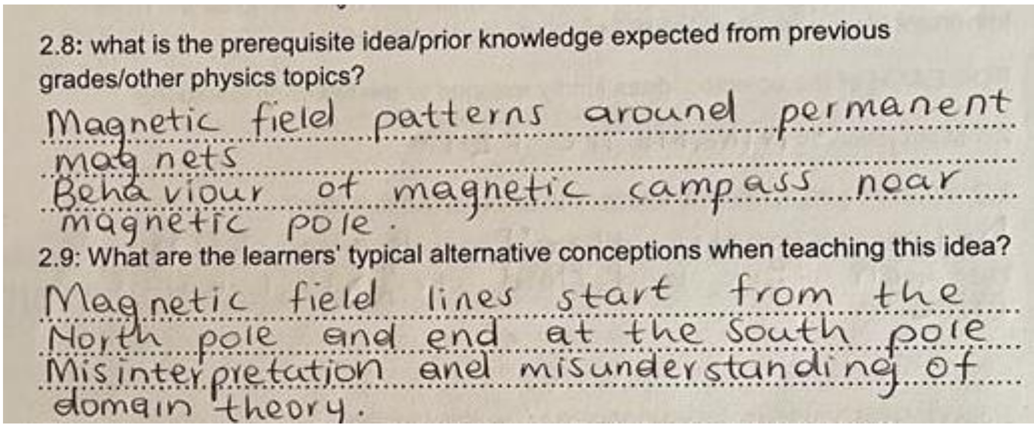
Production of emf relies on changing magnetic
flux

Figure 4.2.3: Snapshot of TE2's pre-CoRe responses to CS based on the big idea of FL Source: Researcher's own.

The teacher's pPCK for this component based on the two big ideas of MF and FL prior to intervention were scored as '*adequate*'. The reason to justify the score is based on the fact that ‘subordinate ideas are limited to being aware of the definitions, equations or terms’ as stated by the scoring rubric.

4.3.1.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the existence of magnetic field patterns due to field lines around the magnets was cited as the learners’ prior knowledge before the treatment of magnetic flux. The teacher cited the behaviour of a magnetic compass placed closer to a magnetic pole perhaps to predetermine whether a given pole is north or south pole. Misunderstanding of the domain theory was quoted as an alternative conception as it led many learners to presume that field lines originate from the north pole and terminate at the south pole as shown in figure 4.2.4.



2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

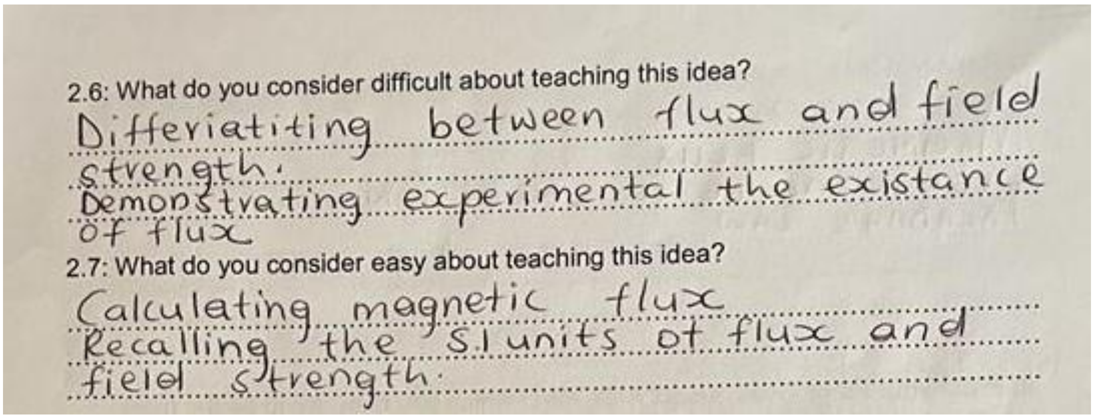
Magnetic field patterns around permanent magnets
Behaviour of magnetic campass near magnetic pole.

2.9: What are the learners' typical alternative conceptions when teaching this idea?

Magnetic field lines start from the North pole and end at the South pole
Misinterpretation and misunderstanding of domain theory.

Figure 4.2.4 Snapshot of TE2’s Pre-CoRe responses regarding knowledge of learner understanding for the big idea of MF. Source: Researcher’s own.

Differentiating between magnetic flux and magnetic field strength was mentioned as being difficult while teaching. Furthermore, the teacher mentioned that the practical demonstration of the existence of flux was not easy when teaching. On the other hand, recall of Systeme International (SI) units and performing calculations using a formula was considered (figure 4.2.5) as something very easy to teach.


2.6: What do you consider difficult about teaching this idea?

Differiatiting between flux and field strength.
Demonstrating experimental the existance of flux

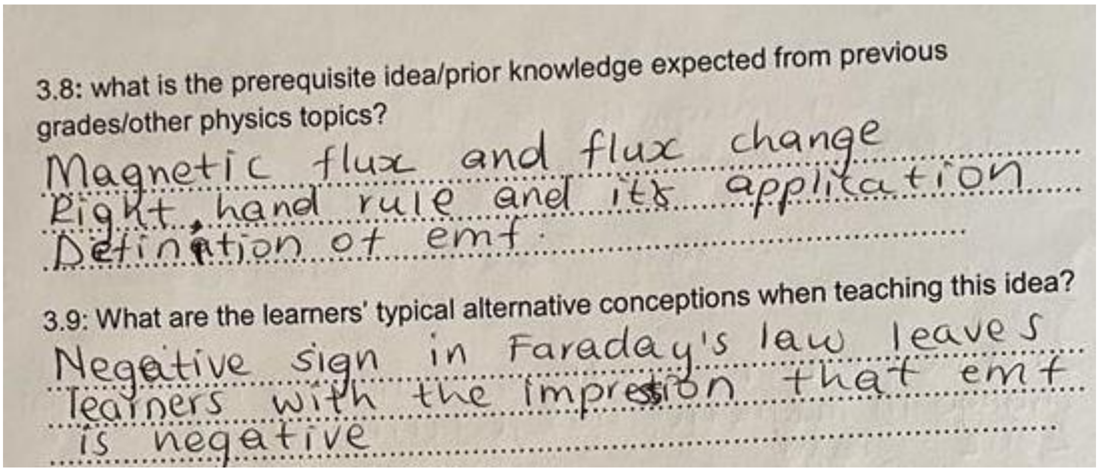
2.7: What do you consider easy about teaching this idea?

Calculating magnetic flux
Recalling the S.I units of flux and field strength.

Figure 4.2.5 Snapshot of TE2's pre-CoRe responses based on knowledge of learner understanding big idea of MF. Source: Researcher's own.

However, he made no mention of whether the significance of the angle of the coil in the flux formula's calculation was easy or difficult to teach. Furthermore, the teacher made no mention of the possible alternative conceptions regarding flux and flux change. Teacher TE2's personal PCK for this component prior to intervention for the big idea MF was scored as '*adequate*'. This is because, as stated by the rubric, 'an appropriate difficulty related to one of the main ideas is identified and clearly formulated '.

For the second big idea of FL, magnetic flux, flux change, application of RHR and definition of EMF were cited as prerequisites for learners to conceptualise EMI and Faraday's law. On the other hand, the physical significance of the negative sign in Faraday's formula was considered a potential source of misconception as some learners may think that the value of EMF is negative as shown in figure 4.2.6


3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

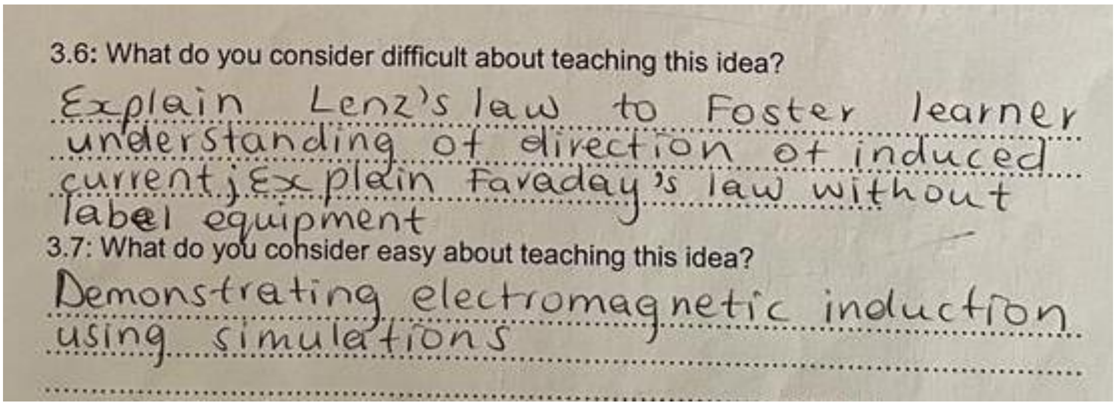
Magnetic flux and flux change
Right, hand rule and its application
Definition of emf.

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Negative sign in Faraday's law leaves learners with the impression that emf is negative

Figure 4.2.6 Snapshot of TE2's pre-CoRe responses regarding *learner understanding* for the big idea of FL. Source: Researcher's own.

TE2 mentioned as shown in figure 4.2.7, the difficulty in explaining Faraday’s law without having any demonstration experiment. An explanation associated with Lenz’s law for the direction of the induced current was also mentioned as a difficult concept to teach. The use of simulations was mentioned as something which makes it easier to demonstrate FL.



3.6: What do you consider difficult about teaching this idea?

Explain Lenz’s law to Foster learner understanding of direction of induced current; Explain Faraday’s law without label equipment

3.7: What do you consider easy about teaching this idea?

Demonstrating electromagnetic induction using simulations

Figure 4.2.7 Snapshot of TE2’s pre-CoRe responses based on learner understanding big idea of FL Source: Researcher’s own.

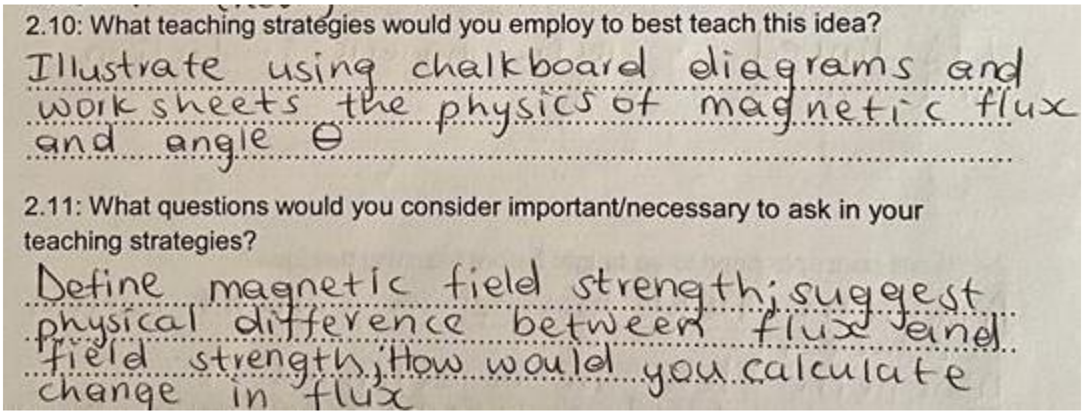
The teacher made no mention of whether or not the application of RHR to predict direction of induced current was easy or difficult during actual teaching.

Consequently, the teacher’s PCK in this component is scored as ‘*adequate*’. This is because, as stated by the rubric, ‘an appropriate difficulty related to one of the main ideas is identified and clearly formulated. ‘

4.3.1.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, the teacher suggested as shown in figure 4.2.8, to employ the use of chalkboard diagrams with explanatory notes and worksheets as a CTS to illustrate magnetic flux and physical significance of angle θ which is contained in the flux formula. Some of the questions suggested to be asked as part of CTS were to be centred on:

- Definition of magnetic field strength.
- Difference between magnetic flux and magnetic field strength.
- Performing calculations of but not limited to flux change using flux formula.



2.10: What teaching strategies would you employ to best teach this idea?

Illustrate using chalkboard diagrams and work sheets the physics of magnetic flux and angle θ

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

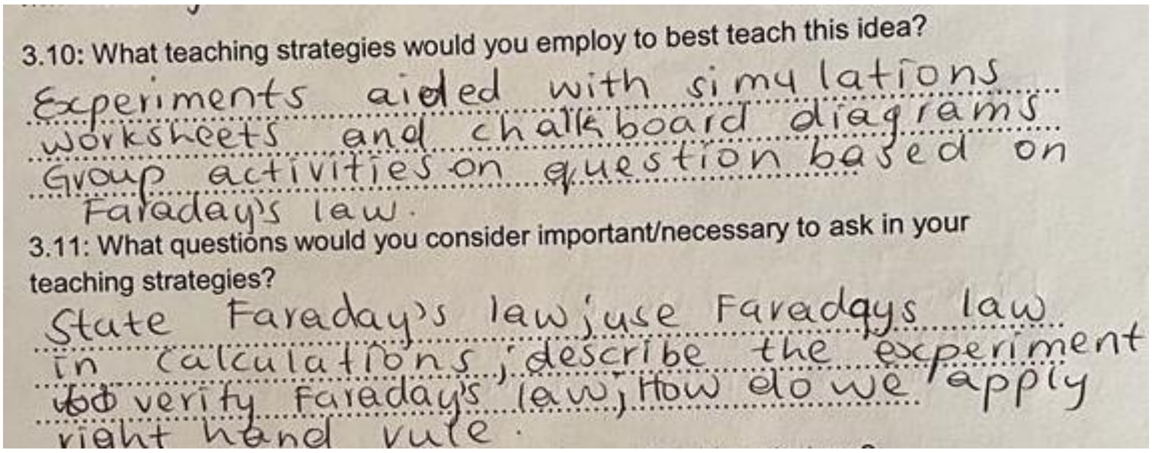
Define magnetic field strength; suggest physical difference between flux and field strength; How would you calculate change in flux

Figure 4.2.8 Snapshot of TE2’s pre-CoRe responses regarding his CTS for the big idea of MF. Source: Researcher’s own.

The teacher’s pPCK for this component based on the first big idea of MF prior to the intervention was therefore scored as ‘*developing*’. This score is justified by the fact that the ‘overall strategy is workable and at least two different levels of representation to enforce an aspect or concept with explanatory notes are suggested’ as stated by the rubric.

For the second big idea of FL, the teacher mentioned (figure 4.2.9) the use of experiments aided by simulations as part of his CTS to be employed to teach EMI to his learners. Furthermore, worksheets, chalkboard diagrams with explanatory notes and, group activities based on calculations using Faraday’s formula were suggested as part of his CTS when teaching Faraday’s law. The proposed guiding questions to be asked as part of his CTS include:

- Stating Faraday’s law of EMI.
- Using Faraday’s formula to perform some calculations.
- Describing experimentally how Faraday’s law can be verified.
- How to apply RHR to predict the direction of induced current.



3.10: What teaching strategies would you employ to best teach this idea?

Experiments aided with simulations
worksheets and chalkboard diagrams
Group activities on question based on
Faraday's law.

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

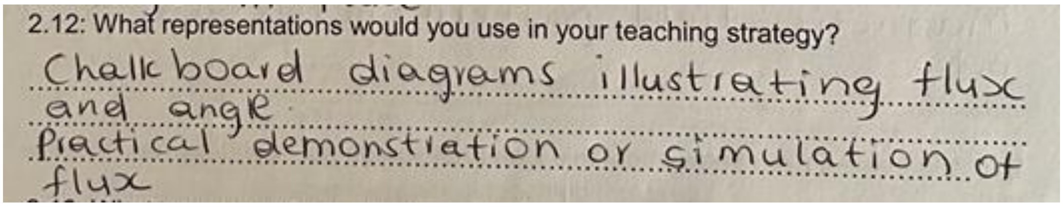
State Faraday's law; use Faradays law
in calculations; describe the experiment
to verify Faraday's law; How do we apply
right hand rule.

Figure 4.2.9 Snapshot of TE2’s pre-CoRe responses regarding his CTS for the big idea of FL. Source: Researcher’s own.

The teacher’s pPCK for this component based on the second big idea prior to intervention was therefore scored as ‘*developing*’. This score is justified by the fact that ‘ at least two different levels of representation to enforce an aspect or concept with explanatory notes are suggested ‘ as stated by the rubric.

4.3.1.4 REPRESENTATIONS

For the first big idea of MF, the teacher proposes in figure 4.2.10 to use chalkboard diagrams aided by explanatory notes for representing magnetic flux and physical significance of symbols used in flux formula. Furthermore, the teacher suggests using practical demonstration and simulations as representations to teach the concept of magnetic flux.



2.12: What representations would you use in your teaching strategy?

Chalkboard diagrams illustrating flux
and angle.
Practical demonstiation or simulation of
flux

Figure 4.2.10 Snapshot of TE2’s pre-CoRe responses regarding his representations for MF. Source: Researcher’s own.

The teacher’s pPCK for this component based on the first big idea of MF prior to intervention was scored as ‘*developing*’. This score is justified by the fact that ‘an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts is presented’ as stated by the rubric.

For the second big idea of FL, the teacher suggests representations involving simulation, graphs and diagrams on the chalkboard supported by explanatory notes in conjunction with his CTS. The teacher's pPCK for this component prior to intervention was scored as '*developing*' because 'some evidence is given of the use of representations to support conceptual development', as stated in the rubric.

4.3.2 DISCUSSION OF POST-INTERVENTION CoRes

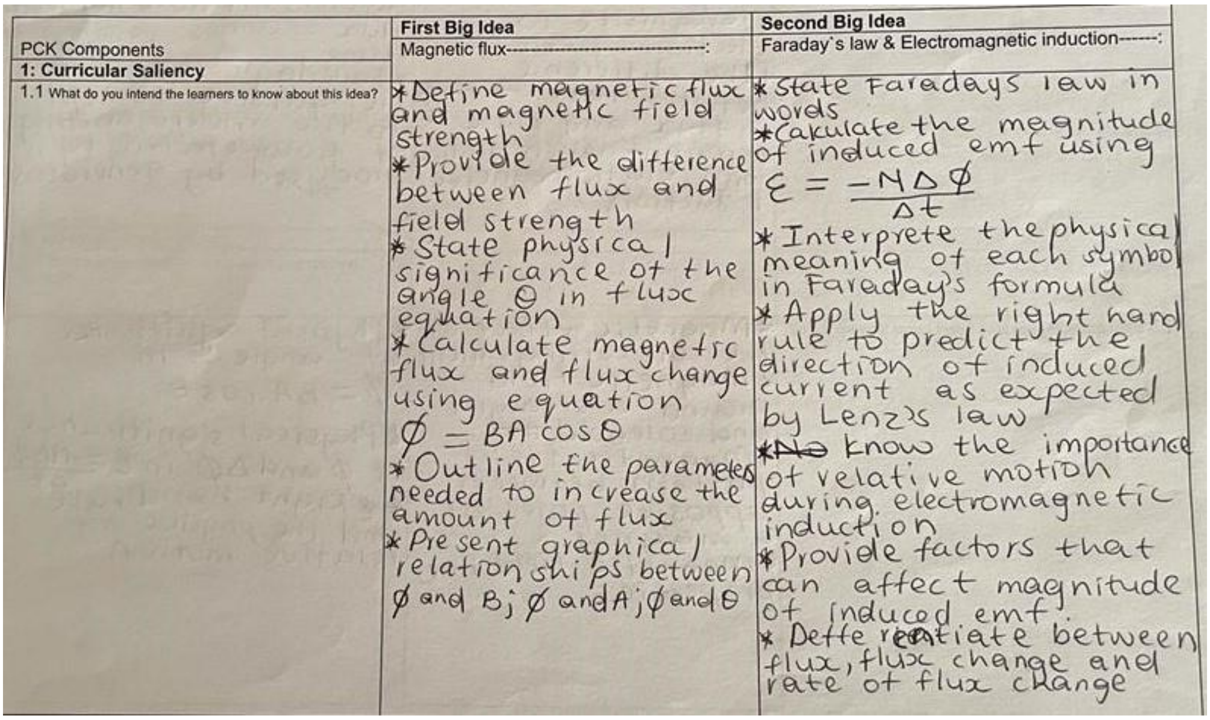
Table 4.2.2 shows the score results obtained after a thorough scrutiny of responses given in TE2's completed post-intervention CoRe based on Grade 11's EMI section of electromagnetism (see Appendix C2). Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.2.2: Scores of TE2 based on post-intervention CoRes.

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency					x			o
2	Learner understanding					x	o		
3	Conceptual teaching strategies							x	o
4	Representations					x			o

4.3.2.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, the teacher presented some details regarding the aspects of his CS as presented in figure 4.2.11.



PCK Components	First Big Idea Magnetic flux---------------------------------:	Second Big Idea Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	*Define magnetic flux and magnetic field strength *Provide the difference between flux and field strength *State physical significance of the angle θ in flux equation *Calculate magnetic flux and flux change using equation $\phi = BA\cos\theta$ *Outline the parameters needed to increase the amount of flux *Present graphical relationships between ϕ and B; ϕ and A; ϕ and θ	*State Faradays law in words *Cakulate the magnitude of induced emf using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ *Interprete the physical meaning of each symbol in Faraday's formula *Apply the right hand rule to predict the direction of induced current as expected by Lenz's law *~~No~~ know the importance of relative motion during electromagnetic induction *Provide factors that can affect magnitude of induced emf. *Defferentiate between flux, flux change and rate of flux change

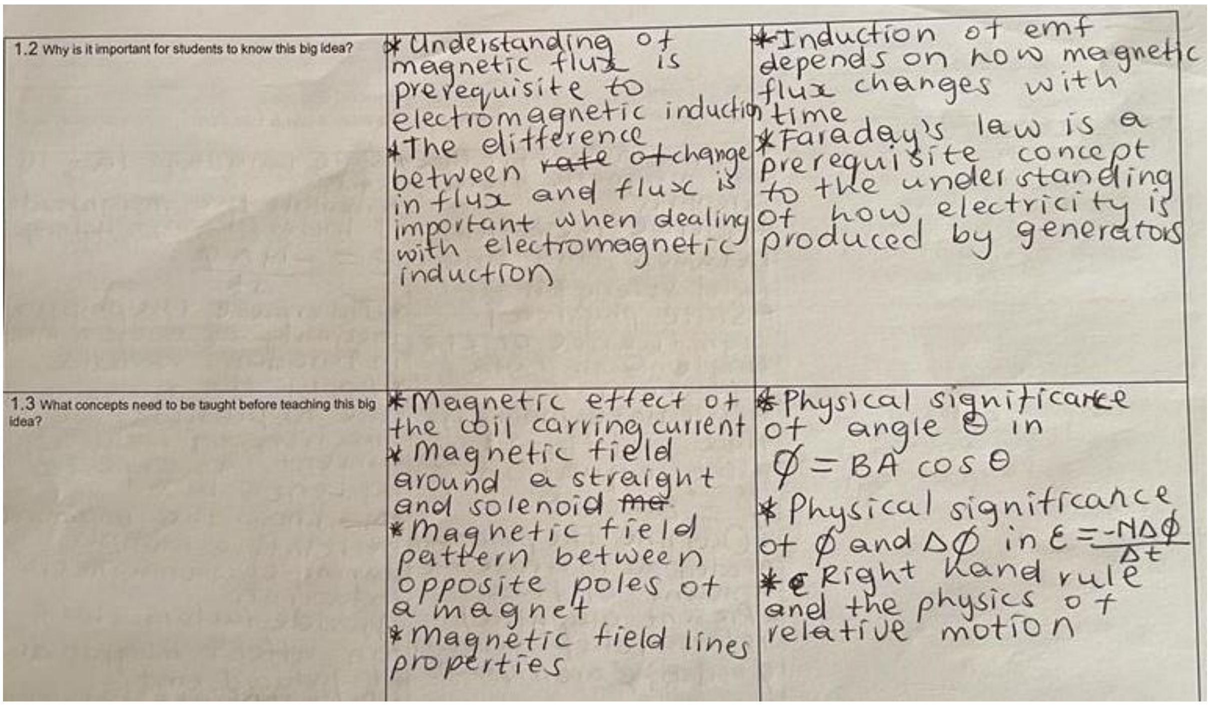
Figure 4.2.11 Snapshot of TE2's post-CoRe responses to question 1.1 regarding CS for MF (left) and FL (right). Source: Researcher's own.

In his post-intervention CoRe while responding to question 1.1, he suggested the definitions, difference between flux and field strength, calculations using the flux formula, and graphical relationships as vital knowledge about magnetic flux for his leaners.

The teacher's pPCK for this component based on the first big idea of MF after the intervention was therefore scored as '*developing*'. This score is justified by the fact that ' there are indications that attention was paid to sequencing of the ideas and the subordinate ideas that account for the application of equations and definitions are identified' as stated by the rubric.

For the second big idea of FL, the teacher's responses based on question 1.1 demonstrated his being experienced in the field as shown in figure 4.2.11. He suggested recall of Faraday's law and formula use, RHR application, significance of relative motion and rate of flux change as important for the learners to know.

Magnetic flux and flux change were cited as concepts which needed to be taught before introducing FL. Furthermore, he mentioned in his response to questions1.2 and 1.3 that relative motion was another necessary concept to be taught to learners before being introduced to the concept of FL of EMI, as shown in figure 4.2.12.



1.2 Why is it important for students to know this big idea?	*Understanding of magnetic flux is prerequisite to electromagnetic induction *The difference between ~~rate~~ of change in flux and flux is important when dealing with electromagnetic induction	*Induction of emf depends on how magnetic flux changes with time *Faraday's law is a prerequisite concept to the understanding of how electricity is produced by generators
1.3 What concepts need to be taught before teaching this big idea?	*Magnetic effect of the coil carrying current *Magnetic field around a straight and solenoid ~~me~~ *Magnetic field pattern between opposite poles of a magnet *Magnetic field lines properties	*Physical significance of angle θ in $\phi = BA\cos\theta$ *Physical significance of ϕ and $\Delta\phi$ in $\mathcal{E} = \frac{-N\Delta\phi}{\Delta t}$ *Right hand rule and the physics of relative motion

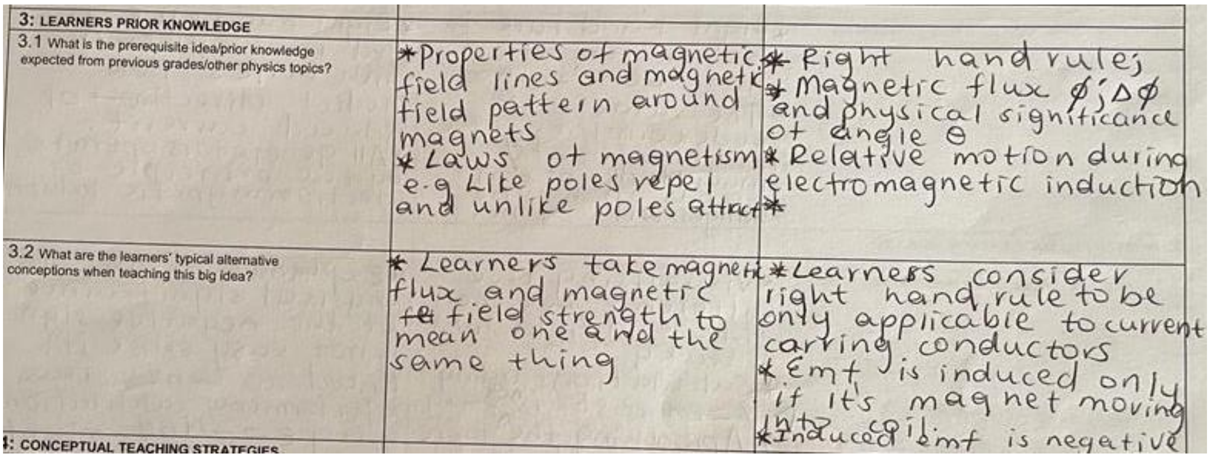
Figure 4.2.12 Snapshot of TE2's post-CoRe responses to question 1.2 &1.3 regarding CS for MF (left) and FL (right). Source: Researcher's own.

Faraday's law was presented (Figure 4.2.12) in his response to question 1.2 as a pre-concept needed for understanding the principle by which generators operate. Furthermore, he mentioned in his response to question 1.4 that the RHR was to be used in conjunction with Lenz's law to determine the direction of the induced current.

The teacher's pPCK for this component based on the second big idea of FL after the intervention was therefore scored as '*exemplary*'. This score is justified by the fact that 'there is evidence of appropriate sequencing of ideas and the subordinate ideas constitute an exhaustive list of concepts to be taught' as stated by the rubric. Furthermore, the 'identified pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the second big idea of FL, as stated in the rubric.

4.3.2.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the teacher cited (figure 4.2.13) the properties of magnetic field lines and field patterns as prerequisite for the learners to understand the flux concept. Laws of magnetism are cited as pre-concepts to be known by learners ahead of the magnetic flux. However, the teacher made no mention of the magnetic effect of coil carrying current as well as magnetic field strength as pre-concepts needed prior to teaching magnetic flux.



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	*Properties of magnetic field lines and magnetic field pattern around magnets *Laws of magnetism e.g Like poles repel and unlike poles attract	*Right hand rule; *Magnetic flux ϕ; $\Delta\phi$ and physical significance of angle θ *Relative motion during electromagnetic induction *
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	*Learners take magnetic flux and magnetic ~~fe~~ field strength to mean one and the same thing	*Learners consider right hand rule to be only applicable to current carring conductors *Emf is induced only if it's magnet moving into coil *Induced emf is negative
4: CONCEPTUAL TEACHING STRATEGIES		

Figure 4.2.13 Snapshot of TE2's post-CoRe responses regarding learner's knowledge of understanding for MF (left) and FL (right). Source: Researcher's own.

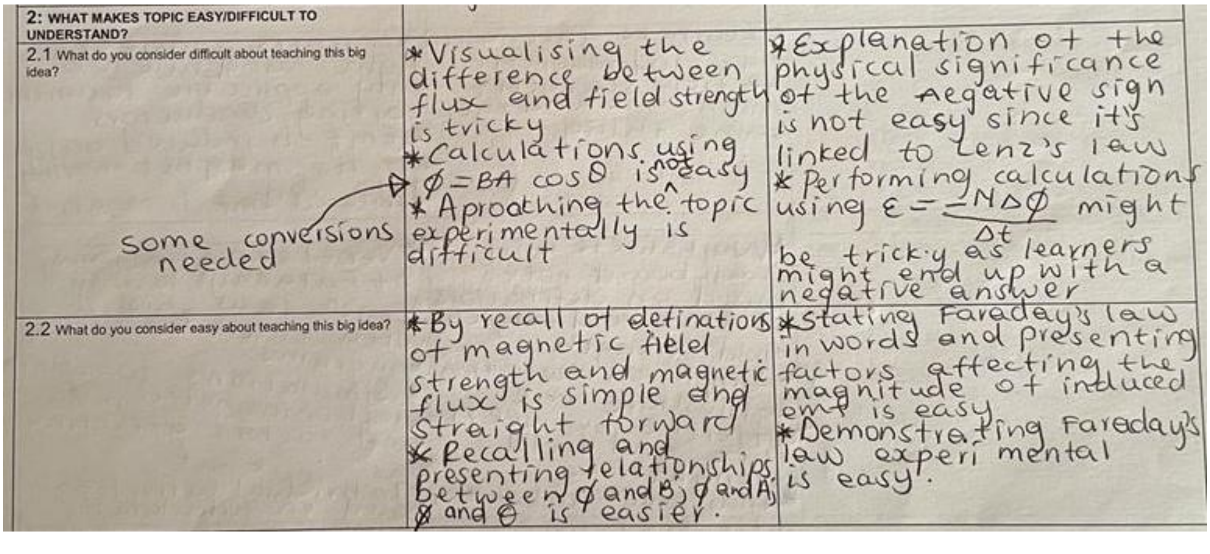
The teacher is aware of the learners' difficulty to distinguish between magnetic flux and magnetic field strength.

The teacher proposes as shown in figure 4.2.14 that teaching magnetic flux experimentally is very difficult as learners do not find it easy to visualise magnetic flux and magnetic field strength. The teacher also refers to calculations using the flux formula as something difficult to teach. Recall of the definition of magnetic field strength and magnetic flux is regarded as easier to teach. Furthermore, the teacher considers the teaching of relationships by graphical methods easy and straight forward.

The teacher's pPCK for this component based on the MF after the intervention was therefore scored as '*developing*'. This score is justified by the fact that 'appropriate difficulties for two of the main ideas are identified and clearly formulated' as stated in the rubric.

For the second big idea of FL, the teacher mentions flux, flux change, physical significance of angle, the RHR, and relative motion as the necessary knowledge needed by the learners prior to their being exposed to EMI and Faraday's law. The RHR was cited as one of the sources of alternative conceptions as some learners consider it to be only applicable to current-carrying conductors. Furthermore, the teacher mentioned that some learners might take it as if EMF is only induced if it is the magnet moving into and out of the coil. The teacher clearly knows that some learners do not appreciate the role of relative motion between the coil and magnet.

TE2 pointed out that the explanation associated with Lenz's law to convince learners about physical significance of the negative sign in the formula was not easy. Furthermore, he indicated that teaching calculations based on EMF was difficult since learners might end up with a negative outcome for which they are not able to account.



2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea? some conversions needed	*Visualising the difference between flux and field strength is tricky *Calculations using $\phi = BA \cos\theta$ is not easy *Aproaching the topic experimentally is difficult	*Explanation of the physical significance of the negative sign is not easy since it's linked to Lenz's law *Performing calculations using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ might be tricky as learners might end up with a negative answer
2.2 What do you consider easy about teaching this big idea?	*By recall of definations of magnetic field strength and magnetic flux is simple and straight forward *Recalling and presenting relationships between ϕ and B, ϕ and A, ϕ and θ is easier.	*Stating Faraday's law in words and presenting factors affecting the magnitude of induced emf is easy *Demonstrating Faraday's law experimental is easy.

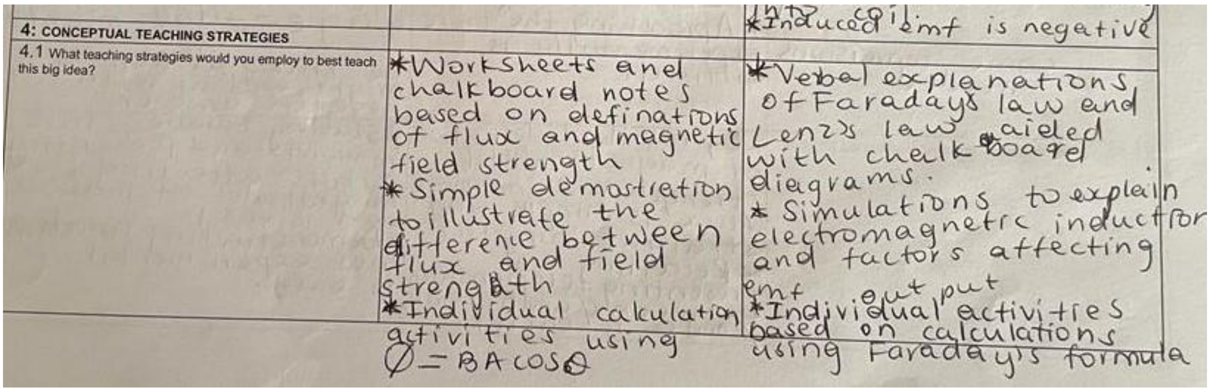
Figure 4.2.14 Snapshot of TE2's post-CoRe responses regarding learner understanding for MF (left) and FL (right). Source: Researcher's own.

In his response to question 2.2, the teacher mentioned in figure 4.2.14 that Faraday's law statement and the factors governing EMF output to learners as easy to perform. Perhaps the teacher thought these were usually associated with low-order questions which only rely on simple recall. While responding to question 2.2, the teacher suggested the experimental demonstration as an easy way to help the learners to conceptualise EMI and Faraday's law. The teacher's pPCK for this component based on the second big idea after the intervention was therefore scored as '*developing*'. This score is justified by the fact that 'appropriate difficulties for two of the main ideas are identified and clearly formulated', as stated in the rubric.

4.3.2.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, worksheets and chalkboard explanatory notes were presented (Figure 4.2.15) as part of CTS to aid the learners' understanding of magnetic flux. The teacher suggested some individual activities based on calculations using the magnetic flux formula as a CTS to enable the learners to independently solve problems. Furthermore, a simple experimental demonstration was suggested as part of CTS to assist learners to differentiate between magnetic field strength and magnetic flux.

As part of his CTS, the teacher suggested in figure 4.2.15 to make use of some questions related to magnetic field strength magnetic flux, and some mathematical relationships.

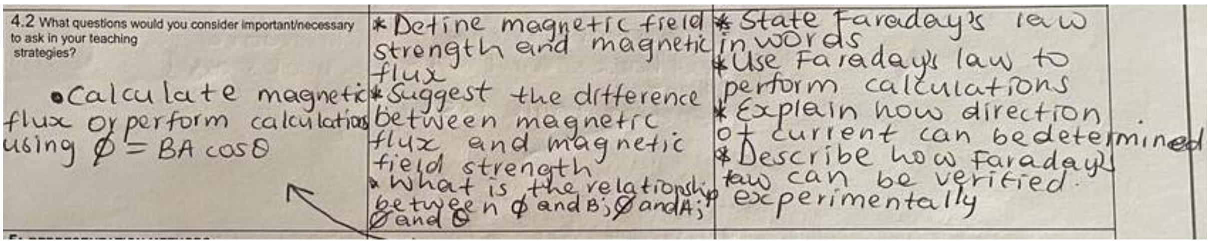


4: CONCEPTUAL TEACHING STRATEGIES		*Induced into coil emf is negative
4.1 What teaching strategies would you employ to best teach this big idea?	*Worksheets and chalkboard notes based on definations of flux and magnetic field strength *Simple demostration to illustrate the difference between flux and field strength *Individual calculation activities using $\emptyset = BA\cos\theta$	*Verbal explanations of Faraday's law and Lenz's law aided with chalk board diagrams. * Simulations to explain electromagnetic induction and factors affecting emf output *Individual activities based on calculations using Faraday's formula

Figure 4.2.15 Snapshot of TE2's post-CoRe responses to question 4.1 regarding CTS for MF (left) and FL (right). Source: Researcher's own.

The teacher's pPCK for this component based on the first big idea was therefore scored as '*exemplary*'. This is because 'the suggested strategy is highly learner centred lesson and there is evidence that the strategy will support conceptual understanding' as stated in the rubric.

For the second big idea of FL, the teacher proposed (figure 4.2.15) to use simulations as an effective CTS approach to demonstrate the EMI and the factors which would enhance greater EMF output. Furthermore, the teacher suggested the traditional verbal explanatory CTS approach aided by chalkboard diagrams and explanatory notes to enable learners to conceptualise Faraday's law and the application of Lenz's law. Individual activities based on calculations using the Faraday’s formula was suggested in figure 4.2.16 as part of CTS necessary for learners to independently solve problems.



4.2 What questions would you consider important/necessary to ask in your teaching strategies? •Calculate magnetic flux or perform calculations using $\phi = BA \cos\theta$	*Define magnetic field strength and magnetic flux *Suggest the difference between magnetic flux and magnetic field strength *What is the relationship between ϕ and B; ϕ and A; ϕ and θ	*State Faraday's law in words *Use Faraday's law to perform calculations *Explain how direction of current can be determined *Describe how Faraday's law can be verified experimentally	

Figure 4.2.16 Snapshot of TE2’s post-CoRe responses to question 4.2 regarding CTS for MF (left) and FL (right). Source: Researcher’s own.

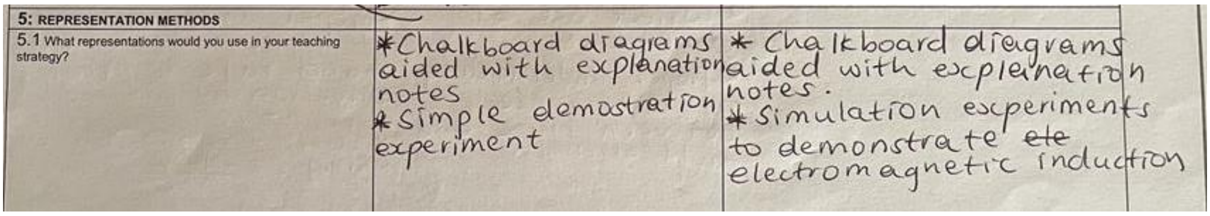
The teacher advocated (figure 4.2.16) to ask questions based on Faraday’s law, formula and direction of the induced current.

The teacher’s pPCK for this component based on the second big idea of FL was scored as ‘*exemplary*’. This is because the ‘use of macroscopic, visual and symbolic representations to enforce aspect(s) of a concept are given with explanatory notes’, as stated in the rubric.

4.3.2.4 REPRESENTATIONS

For the first big idea of MF, shown in figure 4.2.17, the teacher suggested to use chalkboard diagrams aided by explanatory notes as the representation to be adopted as part of his CTS. Furthermore, the teacher proposed to make use of demonstration experiment as a representation. However, the teacher did not go further to elaborate on the kind of experiment he would carry out to demonstrate the concept of flux.

The teacher’s pPCK for this component, based on the first big idea of MF, was scored as ‘*developing*’ after the intervention. This is because he suggested ‘an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts is presented’, as stated in the rubric.



5: REPRESENTATION METHODS			
5.1 What representations would you use in your teaching strategy?	*Chalkboard diagrams aided with explanation notes *Simple demostration experiment	* Chalkboard diagrams aided with explanation notes. *Simulation experiments to demonstrate ~~ete~~ electromagnetic induction	

Figure 4.2.17 Snapshot of TE2’s post-CoRe responses regarding representation for MF (left) and FL (right). Source: Researcher’s own.

For the second big idea of FL, simulation experiments to demonstrate EMI were suggested (figure 4.2.17) as the representation for an effective CTS. The teacher further suggested to make use of chalkboard diagrams aided by explanatory notes as another way of representation to be adopted as part of his CTS.

The teacher's pPCK for this component, based on the second big idea of FL, after the intervention was scored as '*exemplary*'. This is because 'extensive use of representations (visual and symbolic / graphical / pictorial / diagrammatic) to enforce specific aspect(s) of concepts being developed are suggested', as stated in the rubric.

4.3.3 COMPARISON OF TE2's PRE- and POST-INTERVENTION CoRes

Table 4.2.3 Summary of TE2's pre- and post-intervention personal PCK scores

PCK Components	**PCK Scoring level summary**															
	PRE-CoRe								**POST-CoRe**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency			x	o									x			o
Learner understanding			x	o									x	o		
Conceptual teaching strategies					x	o									x	o
Representations					x	o							x			o

In Table 4.2.3, the immediate observation is that the PCK scores shifted from predominantly developing (D) and adequate (A) in pre-intervention CoRe to predominantly developing (D) and exemplary (E) in post-intervention CoRe. The post-CoRe scores highlighted in yellow show which scores improved after the intervention compared to pre-CoRe scores. This gives the general impression that the intervention had an impact on the way TE2 constructed his post-intervention CoRes.

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in Table 4.1.4. Table 4.2.4 shows the comparative PCK scores on a numerical scale.

Table 4.2.4: Comparison of TE2's PCK scores on a scale ranging from 1 to 4.

PCK Components	**Scores**					
	Pre-CoRe			**Post-CoRe**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	2	2	2.0	3	4	3.5
Learner understanding	2	2	2.0	3	3	3.0
Conceptual teaching strategies	3	3	3.0	4	4	4.0
Representations and analogies	3	3	3.0	3	4	3.5
Total (16)	10	10	10.0	13	15	14.0
Average (4)	2.5	2.5	2.5	3.3	3.8	3.5

There was a difference between pre-CoRe scores and post-CoRe scores based on the big idea of MF. The scores increased by an average of 0.8 points (from a score of 2.5 to 3.3). Furthermore, there was a noticeable difference between the pre-CoRe scores and post-CoRe scores that was observed based on the second big idea of FL. The scores increased by an average of 1.3 points (from a score of 2.5 to 3.8) after the intervention. Combining the two big ideas, the overall average score increased by 1.0 points (from 2.5 for pre-CoRe to 3.5 for post-CoRe). This is evidence that the intervention had an impact in the way TE2 constructed his CoRes based on EMI prior to teaching it.

4.3.4 VIDEO-RECORDED LESSON OBSERVATIONS: THE CASE OF TE2.

The transcript of the video-recorded lesson is available in Appendix D2. Six sections were identified from his video-recorded lesson. Having also taught the Grade 11 section of electromagnetism for many years, he had vast experience of approaching the EMI section. TE2 managed to treat both the first and second big ideas of MF and FL in just one lesson taking 69mins 35s.

Section 1: Introduction revision of knowledge based on the previous lesson. [5 min 13 sec]

The introductory discussion touched on recapping Grade 10 section magnetism, magnetic field strength and magnetic field patterns as depicted by figure 4.2.18.

Figure 4.2.18: Screenshot of TE2 recapping Grade 10 magnetism with Grade 11 learners. Source: Researcher’s own.

In his introduction he reminded learners about the section which he had just completed based on the magnetic effect of a coil carrying current. The overall class discussion involved how to apply the RHR if confronted with either a straight or looped conductor carrying current. Some of the questions he asked his learners were based on the application of the RHR to the straight conductor and solenoid carrying current.

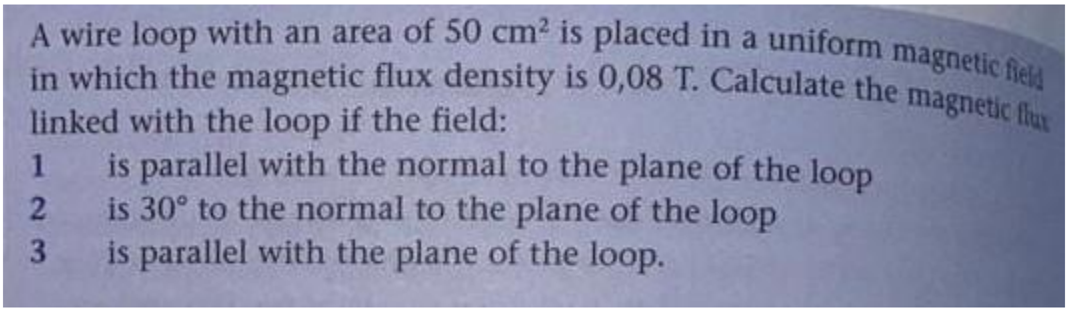
Section 2: Teaching the first big idea of magnetic flux followed by a short classwork assessment [19 min 56 sec]

He then introduced the first big idea of MF and its interrelatedness to magnetic field strength. He started with a definition of magnetic flux which he wrote on the chalkboard. He then went on to verbally explain to the learners the link between magnetic field strength and magnetic flux. He provided the mathematical formulations of magnetic flux and explained the physical meaning of each of the symbols. He went further to explain the physical significance of magnetic flux and the difference between magnetic field strength and magnetic flux.

His CTS involved verbal explanations accompanied by use of brief chalkboard explanatory notes. He led a discussion to guide learners in solving problems involving the flux formula. While working on examples which involved the MF formula, he verbally emphasised:

> *When performing a calculation of the flux please don’t just use any given angle. Remember that the angle to be used in our calculations should lie between an imaginary line drawn normal to the loop and the magnetic field. For maximum MF,* θ*=0. For minimum MF,* θ*=90.*

However, no chalkboard diagrams related to angle were presented by the teacher. The teacher then gave his learners a class activity to assess their ‘understanding of MF. Figure 4.2.19 is a snapshot of one of the worksheet questions which the learners answered as individuals in their classwork books.



A wire loop with an area of 50 cm^2 is placed in a uniform magnetic field in which the magnetic flux density is 0,08 T. Calculate the magnetic flux linked with the loop if the field:

1 is parallel with the normal to the plane of the loop
2 is 30° to the normal to the plane of the loop
3 is parallel with the plane of the loop.

Figure 4.2.19: Snapshot of questions based on the big idea of MF. Source: Researcher’s own.

A time frame was given for learners to complete the given task based on MF. While the learners were busy responding to the questions in their workbooks, TE2 went around checking and monitoring progress as well as assisting individual learners. The teacher then requested for clarity-seeking questions before introducing the second big idea of FL. However, no questions were asked by the learners.

<u>Section 3:</u> Teaching the second big idea based on Faraday’s law of EMI using chalkboard diagrams aided by explanatory notes [18 min 12 sec]

The teacher started off by revisiting and verbally explaining the RHR concept and the big idea of MF before introducing the big idea of FL. During the VSRI session, he later on commented on his CTS approach:

> *The only way I can make my learners to understand Faraday’s law of electromagnetic induction is to make sure that they understand the application of the right-hand rule since it is needed to predict the direction of the induced current*

TE2 then went on to introduce Faraday’s law of electromagnetic induction while emphasising the interrelatedness to magnetic flux. In his introduction he started off by briefly explaining how Faraday devised the idea of induction. The teacher made full use of the whiteboard to present diagrams to aid his explanations of FL. Figure 4.2.20 shows the teacher unpacking Faraday’s law to his learners.

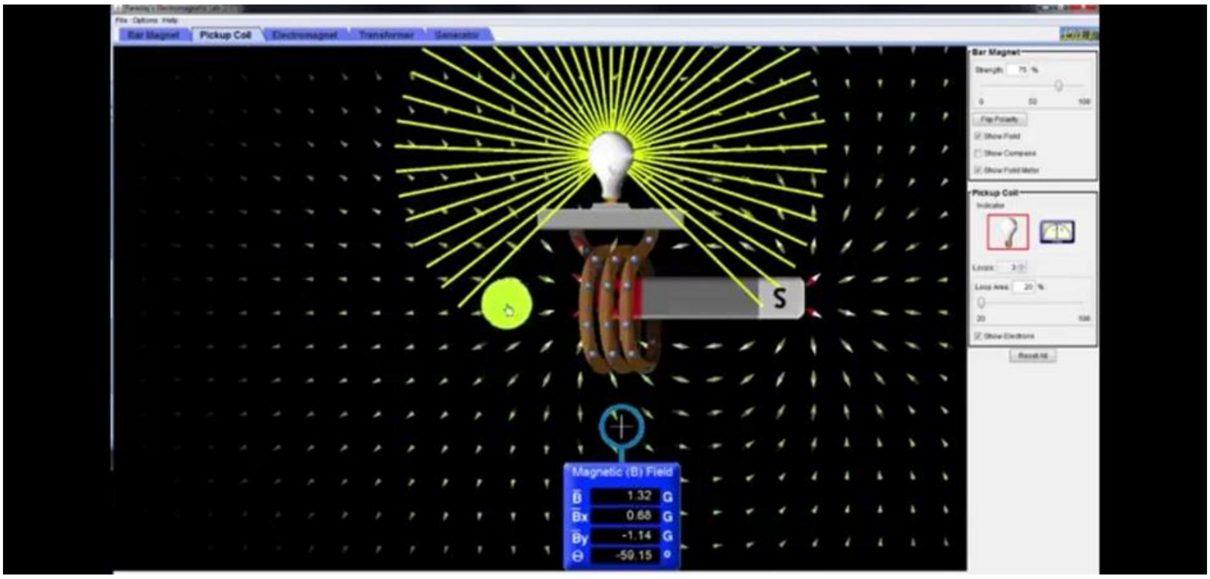
Figure 4.2.20: Screenshot showing a teacher unpacking the FL concept to his learners. Source: Researcher’s own.

While still making full use of the chalkboard as a teaching aid, he then went on to present Faraday’s law statement. This was followed by the mathematical formulations of Faraday’s law on the chalkboard accompanied with some explanatory notes based on the physical significance of each symbol. The teacher took the opportunity to explain the physical significance of the negative sign in Faraday’s formula.

> *There is another law which is directly associated with Faraday's law. It is referred to as Lenz's law. Lenz's law the primary reason as to why we have a negative sign in this formula. According to Lenz's law, the negative sign has to do with the direction of the induced current due to a change in magnetic flux. The direction of the induced current can be predicted by using the right-hand rule.*

Section 4: Teaching the second big idea based on Faraday's law and EMI: PhET simulations [9 min 4 sec].

The teacher went further to represent the second big idea of FL using computer simulation methods as part of his CTS. The simulations attracted the learners' attention and triggered higher levels of their participation. Figure 4.2.21 is a screenshot of a simulation based on the second big idea of FL showing a bulb glowing as the magnet moves into the loop.



$\bar{B}$ 1.32 G
$\bar{B}x$ 0.68 G
$\bar{B}y$ -1.14 G
Θ -59.15 °

Figure 4.2.21: Screenshot of a simulation showing a bulb glowing as magnet moves into the solenoid. Source: Researcher's own.

The teacher emphasised how the RHR should be used together with Lenz's law for predicting the direction of the induced current during simulation presentation:

> *Please note that Lenz's law and the right-hand rule work hand and glove together. The direction of the induced current is predicted by Lenz's law. When applying the right-hand rule, we only consider the field of the induced current, not to the field of the bar magnet.*

The teacher took the simulation opportunity to explain the big idea of MF:

> *If you check the white arrow-shaped spots appearing on the simulation screen and passing through the loop, those arrows are representing magnetic flux.*

However, this statement includes a mistake on his side; the growing arrows represent the changing field, not the flux. The mistake may contribute to the learners' challenge to distinguish between field and flux.

During the VSRI session, he reiterated the importance of varied representations as part of CTS when teaching abstract concepts such as FL:

> *In addition to the chalkboard diagrams supported with explanatory notes, I also co-opted to make use of PhET simulations to further clarify the concept of Faraday's law. During the simulation presentation, I also managed to grab the attention of all my learners and enabled them to observe the phenomenon of electromagnetic induction.*

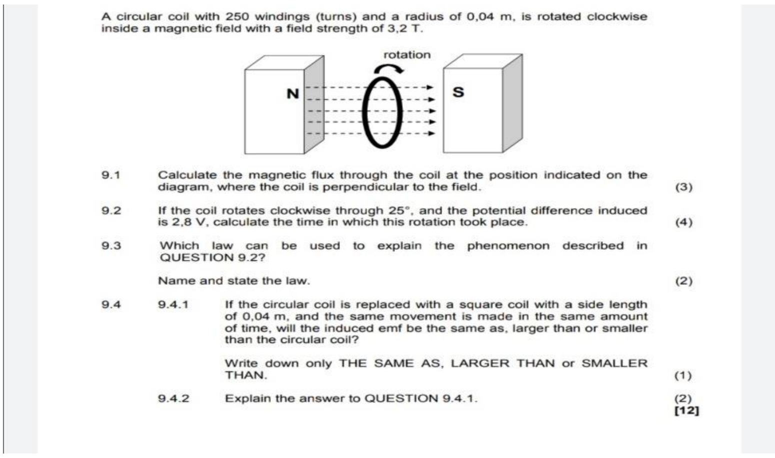
The simulation enabled the learners to understand the conditions which can favour a higher EMF output. This was achieved through varying several parameters such as number of coil turns; magnetic field strength; cross-sectional area of the loop and the speed of relative motion between coil and magnet.

Section 5: Administration of class activity based on Faraday's law [13 min 7 sec]

The teacher went on to present some numerical calculation examples based on Faraday's formula on the chalkboard. He stressed the importance of change in magnetic field when calculating EMF. The teacher then tasked his learners to individually attempt to answer two questions in their classwork books. The sampled questions based on Faraday's law were from their worksheets. Figure 4.2.22 shows one of the questions which was given to learners as classwork. Before the learners responded to the question in figure 4.2.22, the teacher made some remarks:

> *Please note that this question is poorly structured. Actually, the field lines should pass through the loop. Here in this question, it seems like the loop is parallel to the magnetic field. That is not supposed to be the case.*

While learners were busy with the class activities from their worksheets the teacher took the opportunity to assist individual learners with calculations and further explanations.



A circular coil with 250 windings (turns) and a radius of 0,04 m, is rotated clockwise inside a magnetic field with a field strength of 3,2 T.

9.1 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the field. (3)

9.2 If the coil rotates clockwise through 25°, and the potential difference induced is 2,8 V, calculate the time in which this rotation took place. (4)

9.3 Which law can be used to explain the phenomenon described in QUESTION 9.2?

Name and state the law. (2)

9.4 9.4.1 If the circular coil is replaced with a square coil with a side length of 0,04 m, and the same movement is made in the same amount of time, will the induced emf be the same as, larger than or smaller than the circular coil?

Write down only THE SAME AS, LARGER THAN or SMALLER THAN. (1)

9.4.2 Explain the answer to QUESTION 9.4.1. (2)

[12]

Figure 4.2.22: Snapshot of full question based on the big idea of FL. Source: Researcher's own.

<u>Section 6:</u> Concluding the lesson. [4min 03 sec]

The teacher concluded by providing a summary of the entire lesson. He mentioned the application of EMI in electric generators. More practice questions from Grade 11 past examination papers based on magnetic flux and Faraday's law were then given as part of homework.

4.3.5 TEACHER TE2'S VSRI RESPONSES.

The transcript of the VSRI session is available in Appendix E2. The VSRI session was held at TE2's school a day after the video-recorded lesson observations had been concluded. During the VSRI session he was given the chance to reflect on the lesson while referring to the playback from video-recordings. Furthermore, the VSRI session accorded the teacher an opportunity to justify some of his actions during PCK enactment. When asked why he opted to include Grade 10 magnetism in his introduction the teacher said:

> *For learners to have a clear mental picture of the magnetic flux, first and foremost I wanted to remind them magnetic field strength before introducing magnetic flux. The reason being that flux focus mainly on magnetic field strength or field density through a loop of a specific cross-sectional area.*

While presenting the first big idea based on the flux the teacher used chalkboard diagrams aided by explanatory notes for representations. In other words, there were no experiments or demonstration in his CTS as was reported in his post-CoRe. The teacher acknowledged the concern and remarked:

> *I didn't carry out a separate demonstration that was specifically focusing on the first big idea of magnetic flux. However, during the simulation experiments which were*

> *mainly centred on Faraday's law, I did mention and further clarified the concept of magnetic flux.*

His video presentation based on magnetic flux and the associated examples that he worked for his learners were quite clear and relevant to the Grade. When requested to comment on his level of satisfaction with the kind of questions which he asked as part of his CTS, he commented:

> *The kind of questions I asked were quite relevant. In fact, most of my questions especially during simulation presentation provoked higher order kind of thinking. For instance, one such question was related to 'how the direction of induced current can be predicted. While the other question was related to why the galvanometer deflects in the opposite direction to the direction of the magnet.*

However, TE2's comment is not quite clear as it seems to suggest that the galvanometer needle moves into or out of the coil. This might mislead some learners to think that the deflection of the needle is opposite to "the motion of the magnet. The teacher implied that if the magnet reverses its direction, the deflection of the needle also reverses its deflection.

Furthermore, the teacher was happy and satisfied with the explanation regarding the negative sign in Faraday's formula. The class activity which he gave to his learners based on the second big idea of FL was relevant.

The teacher applauded the effectiveness of the VSRI approach by saying that it promoted an evidence-based kind of teaching:

> *It is indeed an effective way of promoting one's professional growth since one would be able to critically observe and reflect on strengths and weaknesses through use of video evidence of the lesson.*

In his responses during the VRSI session, the teacher acknowledged his strengths and weaknesses based on how he delivered the lesson.

4.3.6 SEMI-STRUCTURED INTERVIEW RESPONSES

The transcript of the SSI session is available in Appendix F2. An SSI session was conveniently carried out at teacher TE2's school and in the comfort of his office, after school hours to avoid disrupting his lessons and other school programmes. The SSI session was carried out three days after the video-recorded EMI lesson observation. The teacher responded to all the questions asked during the session. The entire SSI session which was audio-recorded through the teacher's permission lasted for approximately thirty minutes.

In some instances, the teacher gave similar responses to those given during the VSRI session. However, during the SSI session, a lot more was deliberated on regarding the teacher's enactment of PCK. During the SSI session, the teacher reiterated the importance of introducing magnetic flux through giving much emphasis of the learners' understanding of magnetic field strength:

> *The grade 10 physics of magnetism is of paramount importance since its prerequisite to learner's understanding of magnetic flux. Remember that you can only account for the magnetic flux by considering the amount of magnetic field density passing through a loop of cross-sectional area.*

The CTS which the teacher adopted while teaching the first big idea based on MF was more teacher-centred than learner-centred. When asked why he could not demonstrate the concept of MF experimentally or even through simulations, the teacher remarked:

> *Yes, it is true. I could have done better in my conceptual teaching strategy and representations in line with magnetic flux. I think next time I need to improve on that aspect. Although I may seem to be justifying myself, but my verbal explanation was quite convincing. I could tell from their correct response to the class activity which I gave them.*

When asked about the benefits which he might have gained from participating in the study and how he would improve his professional growth, the teacher said:

> *I would like to acknowledge the way CoRes are presented. It makes it much easier to sail through the lesson especially if used in conjunction with lesson preparations and CAPS document.*

The teacher indicated that electromagnetism was one of the abstract sections in Grade 11 Physics, and expressed his concern over the little attention given to it in the CAPS document:

> *To understand the entire process of electricity generation, one needs to start off with the electromagnetic induction principle. However, my only concern is that such an abstract and important section in our modern lives of electricity generation has been made very short in the CAPS document. It is also accorded very few marks even in the examination guidelines.*

The teacher admitted that both the big ideas based on the concepts of MF and FL required thorough preparation on the part of the teacher.

Furthermore, he expressed dissatisfaction with his representations especially while teaching the first big idea of MF to his learners. The teacher went further to suggest the use of real experiments in conjunction with simulations and chalkboard diagrams as representations and part of the CTS:

> *I should also have adopted the experimental approach if our school's laboratory was adequately resourced. However, in my case I had limited options.*

The teacher mentioned the importance of the sequencing of ideas when treating the concept of Faraday's law. During the SSI session, the teacher cited the interrelatedness between *Faraday's law and Lenz's law* and between *Lenz's law and the RHR* as challenges when teaching EMI. Furthermore, he placed emphasis on the importance of using variable CTS when dealing with the concepts of MF and FL.

4.3.7 SCORING ENACTED PCK for TE2

This section discusses and allocates scores to the components of the teacher's ePCK as revealed in the video-recorded lesson reflections during the VSRI and SSI sessions. The discussion shall attempt to link the interrelatedness between the events which occurred during PCK enactment with the expectations from his pPCK as captured through his completion of the post-intervention CoRes. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.2.5: Scores of TE2 based on enacted PCK

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency					x	o		
2	Learner understanding					x	o		
3	Conceptual teaching strategies					x	o		
4	Representations			x			o		

4.3.7.1: KNOWLEDGE OF CURRICULAR SALIENCY

During his lesson presentation based on the first big idea of MF, the teacher started off by reflecting on a previous lesson which was based on the magnetic effect of current-carrying conductors and the RHR. Furthermore, during the lesson he reflected on Grade 10 magnetism before introducing the concept of magnetic flux (see section 4.3.4). During the VSRI session, he commented on his pedagogical approach:

> *I wanted my learners to realise that the section of magnetism is a prerequisite to their understanding of the magnetic flux and to also uproot any possible*

> *misconception which might be in their possession before we unpack the concept of magnetic flux.*

He then went on to introduce the definition of magnetic field strength and magnetic flux. He presented the flux formula together with the physical meaning of each symbol on the chalkboard; the teacher mentioned the SI unit of magnetic flux as weber (Wb) and magnetic field strength as tesla (T). During his lesson, the teacher placed emphasis on the difference between magnetic field strength and magnetic flux.

> *The take-off point is magnetic flux density, which is a measure of the strength and direction of magnetic field. Magnetic field strength deals with strength of the magnetic field. It's a vector quantity. The symbol for magnetic flux density is B, and SI unit of B is the tesla which we represent with a capital T. Magnetic flux by is a product of the component of magnetic flux density perpendicular to the loop and cross-sectional area of the loop. Magnetic flux is a scalar quantity. The SI unit of magnetic flux is called the weber represented by Wb.*

The teacher went further to paraphrase magnetic flux.

> *……In other words, magnetic flux ∅ is a measure of the total magnetic field lines passing a loop of predictable cross-sectional area. The stronger the magnetic field B passing through an area of loop A, the higher the magnitude of the magnetic flux.*

TE2 explained the difference between magnetic flux and a change in magnetic flux:

> *As the coil rotates by intercepting magnetic field lines, it means that the magnetic flux through the loop will vary. This variation in magnetic flux due to coil rotation leads to what we call magnetic flux change.*

The physical significance of the angle in the magnetic flux formula and its effect on the flux value was verbally explained to the learners.

> *If an imaginary line drawn normal to the loop is parallel to the magnetic field while the plane of the loop is perpendicular to the magnetic field, then higher magnetic flux will be captured since more field lines will pass through the loop and angle between magnetic field and a line normal to the loop will be 0.*
>
> *If an imaginary line drawn normal to the loop is perpendicular to the field while the plane of the loop is parallel to the field, then no magnetic flux passes through the loop. In other words, the magnetic flux will be identically equal to zero since no field lines will pass through the loop and the angle between magnetic field and a line normal to the loop will be 90.*

During the VSRI session the teacher remarked that:

> *It is quite apparent that learners grasp the conceptual differences especially between magnetic flux and magnetic field strength, magnetic flux and magnetic flux change and physical significance of the angle. This is because all these are pre-concepts central to their ability to grasp the EMI concept.*

His presentation based on the first big idea of MF reflected most aspects of CS as reported in his post-intervention CoRe. Consequently, his ePCK for this component based on MF was scored as '*developing*'. While executing his lesson, one would quickly observe 'there are indications that attention was paid to sequencing of the ideas and reasons provided include evidence of understanding of conceptual scaffolding / sequential development', as stated by the rubric.

For the second big idea of FL, the teacher presented a statement of Faraday's law and its mathematical formula to his learners. The existence of the negative sign in the formula was explained in terms of direction of the induced current as required by Lenz' s law. The application of the RHR to predict induced current direction was explained during the presentation:

> *……..Lenz's law is the primary reason as to why we have a negative sign in this formula. According to Lenz's law, the negative sign has to do with the direction of the induced current due to a change in magnetic flux. The direction of the induced current can be predicted by using the right-hand rule. Meaning that Lenz's law works hand and glove with the right-hand rule.*

However, his explanation is inadequate as it does not make it clear to the learners that the induced field should be such as to oppose the changing flux. He did not explicitly mention that the thumb should align with the field of the induced current while explaining the RHR.

The teacher finally went through examples related to FL and numerical calculations using Faraday's formula (see section 5 of his video-recorded lesson). The class activity given for assessment purposes was based on Faraday's law. The teacher enacted his PCK according to his reported CS in his post-intervention CoRe. In other words, the way he executed his lesson based on SBI reflected most aspects of CS as reported in his post-intervention CoRe.

Consequently, his ePCK for this component based on FL was scored as '*developing*'. This score is justified by the fact that 'subordinate ideas that account for the application of equations and definitions are identified', as stated in the rubric. Furthermore, the 'content knowledge is evident ' as stated in the rubric.

4.3.7.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the teacher introduced the lesson through reflecting on the previous lesson which was based on the magnetic effect of a coil carrying conductor. He then went on to present a simple diagram of a bar magnet and asked a learner to come to the front to draw magnetic field lines. While responding to one of the VSRI questions regarding his approach, the teacher indicated that:

> *My intention was to check whether the learners had some alternative conceptions related to magnetism before I introduce the concept of magnetic flux to them. As you know learners tend to demonstrate poor understanding of the domain theory. That is why they end up presuming that magnetic field lines originate from the north pole and terminate at the south pole.*

During his lesson based on the magnetic flux calculations, the teacher placed emphasis on the symbol $\varnothing$. The teacher reminded his learners about the vectorial nature of the magnetic field, and placed more emphasis on the resolution of vectors while explaining the physical significance of angle θ:

> *The take off point is magnetic field strength, which is a measure of the strength and direction of magnetic field. Magnetic field strength deals with strength of the magnetic field. It's a vector quantity. …… θ is the angle between magnetic field and a line normal to the loop….*

His examples to the learners included tricky questions involving the angle θ. The teacher gave individual attention during the time when learners were participating in a class activity based on calculations involving the flux formula, hence most learners managed to successfully perform the calculations. The teacher verbally explained the difference between magnetic flux and magnetic field strength without any form of chalkboard diagram or sketch.

……. Magnetic field strength deals with strength of the magnetic field. It's a vector quantity. …… Magnetic flux by is a product of the component of magnetic flux density perpendicular to the loop and cross-sectional area of the loop…….

Consequently, his ePCK of this component based on MF was scored as '*developing*'. This score is justified by the fact that 'appropriate difficulties were identified and clearly formulated' as stated in the rubric.

For the second big idea of FL, the teacher started by reflecting on the application of the RHR for a solenoid carrying current. He then went on to recap the concept of the magnetic flux before introducing Faraday's law. He justified his approach during the VSRI session saying that:

> *The only way I can make my learners to understand Faraday's law of electromagnetic induction is to make sure that they understand the application of the right-hand rule since it is needed to predict the direction of the induced current.*

Furthermore, he reiterated the importance of the RHR in predicting the direction of the induced current while teaching about Faraday's law. However, the teacher seems to have overlooked the idea of change in magnetic flux per second as the major determinant of EMF output. He later mentioned it during the SSI session that:

> *What is of paramount importance is for learners to understand that the rate at which magnetic flux changes is directly associated with the magnitude of emf output. Yes, it's not magnetic flux which determines emf output, but it's the rate at which the magnetic flux changes.*

Consequently, his ePCK for this component based on FL was also scored as '*developing*'. This score is justified by the fact that 'appropriate difficulties were identified and clearly formulated' as stated in the rubric.

4.3.7.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, the teacher used the chalkboard diagrams aided by verbal and explanatory notes as part of his CTS to execute his lesson based on magnetic flux. The teacher explained the whole concept of the magnetic flux while being aided by textbook, chalkboard diagrams and explanatory notes. Evidence gathered from video-recorded lesson observations indicates that most of the guiding questions which he asked his learners were as prescribed in his post-intervention CoRe.

Some assessment questions were presented verbally while others were posed as written assessment. However, the CTS used resulted in more of a teacher-centred lesson as the teacher did most of the talking.

Consequently, the teacher's ePCK in this component based on MF was scored as '*developing*'. This is because 'the overall strategy is workable with at least one aspect related to curriculum saliency or sequencing being considered' as described by the rubric. Furthermore, 'at least two suggested different levels of representation to enforce an aspect or concept with explanatory notes are adopted' as stated by the rubric.

For the second big idea of FL, the teacher utilised the chalkboard to explain Faraday's law concept to the learners as part of his CTS. Faraday's formula was presented, and the physical meaning of each symbol explained including the negative sign in the formula.

The teacher managed to use the whiteboard to successfully explain Lenz's law in terms of the direction of the induced current. He mentioned the interrelatedness between Lenz's law and the direction of the induced current. The teacher also explained Lenz's law to his learners in conjunction with Faraday's law to clarify a way of predicting the direction of the induced current using the RHR, applied to the induced current and the induced field (see section 4.3.4).

> *………... To predict the direction of the induced current we apply the right-hand rule. Meaning that Lenz's law works hand and glove with the right-hand rule. …………..*

The teacher made use of PhET simulations during presentation as part of his CTS to reinforce learners' understanding of EMI and Faraday's law. The teacher reiterated during the SSI session that:

> *I used the PhET simulations during my lesson on Faraday's to further reinforce the EMI concept to my learners.*

The simulation assisted in clarifying how EMF is induced. Furthermore, factors governing EMF output were observed and discussed. Figure 4.2.23 shows a screenshot of a magnet moving into a coil connected to a voltmeter registering an observable reading.

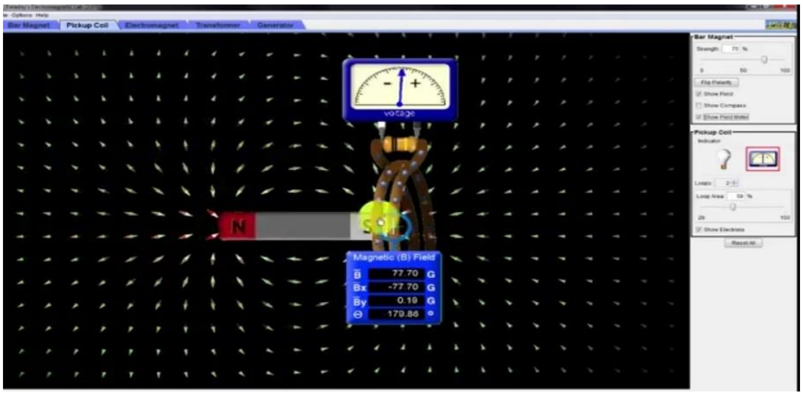


Figure 4.2.23 Screenshot from simulation showing deflection of voltmeter when a magnet moves into the coil. Source: Researcher's own.

The visual animations associated with Physics Education Technology (PhET) simulations increased their level of attention and degree of participation. Most of the questions asked of learners during the EMI simulation presentation were thought-provoking. The teacher made use of chalkboard diagrams to aid in explaining Lenz's law and the direction of current as shown in figure 4.2.24.

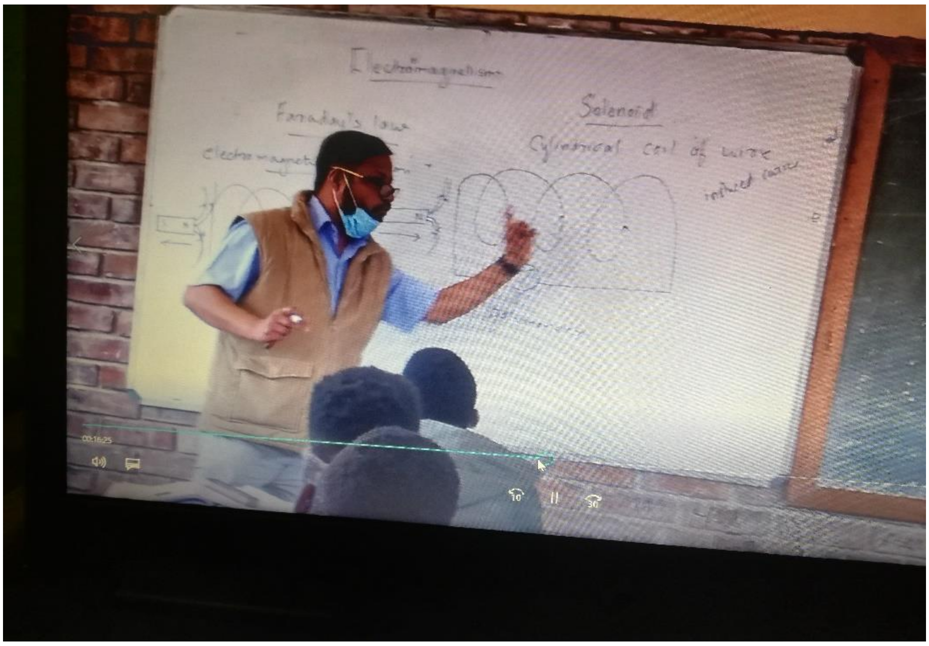


Figure 4.2.24: Screenshot from video lesson showing teacher explaining direction of the induced current to his learners. Source: Researcher's own.

However, in his chalkboard diagram, the third dimension is not visible. Therefore, his diagram was not too helpful to determine the current direction while explaining how to use Lenz's law and the RHR. Furthermore, the teacher did not explicitly say that the thumb should align with the field of the induced current, not the field of the bar magnet. His explanation was merely verbal with no attempt to demonstrate the RHR with his fingers.

Consequently, the teacher's ePCK in this component based on FL was scored as '*developing*'. This is because as stated in the rubric 'the overall strategy is workable'. Furthermore, ' there was evidence of encouragement of learner involvement', as stated by the rubric.

4.3.7.4 REPRESENTATIONS

For the first big idea of MF, the teacher made effective use of chalkboard diagrams supported with explanatory notes to execute his lesson based on magnetic flux.

Furthermore, he made use of simulations (see figure 4.2.25) as representations to further clarify the concept of flux. However, the teacher made no attempt to explain to his learners that real experiments based on magnetic flux were difficult to conduct, hence the ePCK for this component based on MF was awarded a score of '*adequate*'. This is because 'the selection of representations (visual or symbolic) is insufficient', as stated in the rubric.

For the second big idea of FL, the teacher made use of chalkboard diagrams for representations and analogies and as part of his CTS to aid in explaining Faraday's law. In addition to chalkboard diagrams, the teacher adopted PhET simulations for representations and as part of his CTS to demonstrate to learners how EMF is induced in accordance with Faraday's law. Figure 4.2.25 is a screenshot showing the simulated EMI process with a magnet moving relative to the coil.

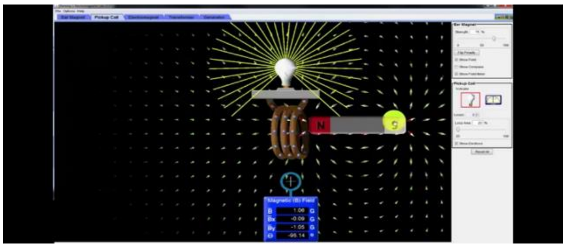


Figure 4.2.25: Screenshot from simulation showing simulated EMI process with magnet moving relative to the coil. Source: Researcher's own.

The simulation experiment assisted in helping learners to observe how the magnitude of EMF could be optimised, as shown in figure 4.2.25. However, the chalkboard diagram was not effective. The learners could not visualise the third dimension. It is not clear which side of the solenoid's turns are at the front, so the current direction was ambiguous. Furthermore, no real experiment based on Faraday's law was conducted as suggested in his post-CoRe, hence the ePCK for this component based on FL was awarded a score of '*developing*'. This is because 'an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts is presented' as stated in the rubric.

4.3.8 COMPARISON OF TE2's POST-INTERVENTION CoRes WITH HIS ENACTED PCK

Table 4.2.6: Comparison of TE2's post intervention and enacted PCK scores.

PCK Component	**PCK SCORING LEVEL SUMMARY**															
	POST								**ENACTED**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency					x			o					x	o		
Learner understanding					x	o							x	o		
Conceptual teaching strategies							x	o					x	o		
Representations					x			o			x			o		

From Table 4.2.6, the following observations were made regarding the post-CoRe scores compared to enacted PCK scores.

The immediate observations which one would make is that the PCK scores shifted from predominantly developing (D) and exemplary (E) in post-intervention CoRe to predominantly developing (D) and adequate (A) during the enactment of PCK.

The scores not highlighted at all is an indication that there was no noticeable change in enacted PCK scores compared to post-intervention scores. The scores highlighted in green show a noticeable decrease in enacted scores compared to post-CoRe scores. The green highlighted scores provide evidence that the teacher’s personal PCK was not fully enacted during teaching.

The teacher had reported in his post-intervention CoRe that he was going to make use of demonstration experiments and simulation to teach the MF. Such a CTS was never practically adopted while teaching the MF. When asked during the VSRI the teacher had the following to say:

> *I realised that it was going to need more time to simulate magnetic flux and electromagnetic induction separately. So, I then decided to combine the simulation experiments together with the one related to Faraday’s law and electromagnetic induction and it worked.*

The teacher also mentioned in his post-intervention CoRe that it was not easy to conduct experiments based on magnetic flux and magnetic field strength because learners find it difficult to visualise the difference. However, during enactment of his PCK, no attempt was made by the teacher to try and address such a challenge. He reported in his post-intervention CoRes that he shall adopt simulations for representation as part of his CTS which he did.

Evidence gathered from the video-recorded lesson observations, VSRI session and SSI scheme indicate that TE2’s enacted PCK in the component of CTS more specially based on MF differ from the post-intervention PCK. The teacher tried to justify himself during the VSRI session, saying that his school lacked adequate laboratory equipment needed for demonstration purposes.

The general impression from table 4.2.6 is that there is evidence available in his enacted PCK which suggests that he used some aspects of his improved personal PCK. However, it is evident that the teacher’s personal PCK was not appropriately translated to enacted PCK during teaching and learning.

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in table 4.1.7. Table 4.2.7 shows the comparative PCK scores on a numerical scale.

Table 4.2.7: Summary of TE2's comparative PCK scores in the post-CoRes and in enactment on a scale ranging from 1 to 4.

PCK Components	**PCK scoring levels**					
	Post-CoRe			**Enacted PCK**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	3	4	3.5	3	3	3.0
Learner understanding	3	3	3.0	3	3	3.0
Conceptual teaching strategies	4	4	4.0	3	3	3.0
Representations	3	4	3.5	2	3	2.5
Total (16)	13	15	14.0	11	12	11.5
Average (4)	3.3	3.8	3.5	2.8	3.0	2.9

From the numerical scores in Table 4.2.7, there was a noticeable difference between post-CoRe scores and ePCK scores based on the big idea of MF, decreasing by an average of 0.5 points (from a score of 3.3 to 2.8). Furthermore, there was an even larger difference between post-CoRe scores and ePCK scores that was observed based on second big idea of FL. The enacted PCK scores based on the big idea of FL decreased by an average of 0.8 points (from a score of 3.8 to 3.0) for PCK enactment. Combining the two big ideas, the overall average score decreased by an average of 0.6 points (from 3.5 for post-CoRe to 2.9) for ePCK, indicating that the teacher's personal PCK was ineffectively enacted during teaching.

4.4 THE CASE OF TEACHER TE3

Teacher TE3 is an experienced male in his early 30s. He holds a B Ed degree majoring in Physical Sciences. He joined the Mpumalanga Education Department as a 10 to 12 Physical Sciences and Mathematics teacher in 2016.

TE3 is one of the permanent employees at his current secondary school where English is the language of instruction across the curriculum. The school is in a rural set-up and enrols from Grade 8 to Grade 12. At the time when this study was conducted, the school had an overall enrolment of 905 learners. Teacher TE3 was involved in teaching two Grade 11 Physical Sciences classes each with 45 learners. He has been the only one available and assigned to teach Physical Sciences at his school.

The teacher mentioned during my first visit to his school that he would need at least four hours to complete the Grade 11 topic of electromagnetism. For the purposes of this study, we agreed that one of his Grade 11 lessons based on EMI would be video recorded. The findings based on how he constructed his pre-CoRes, post-CoRes and, later enacted his PCK based on Grade 11 EMI are detailed in the following sub-sections from 4.4.1 to 4.4.8.

4.4.1 PRE-INTERVENTION CoRes

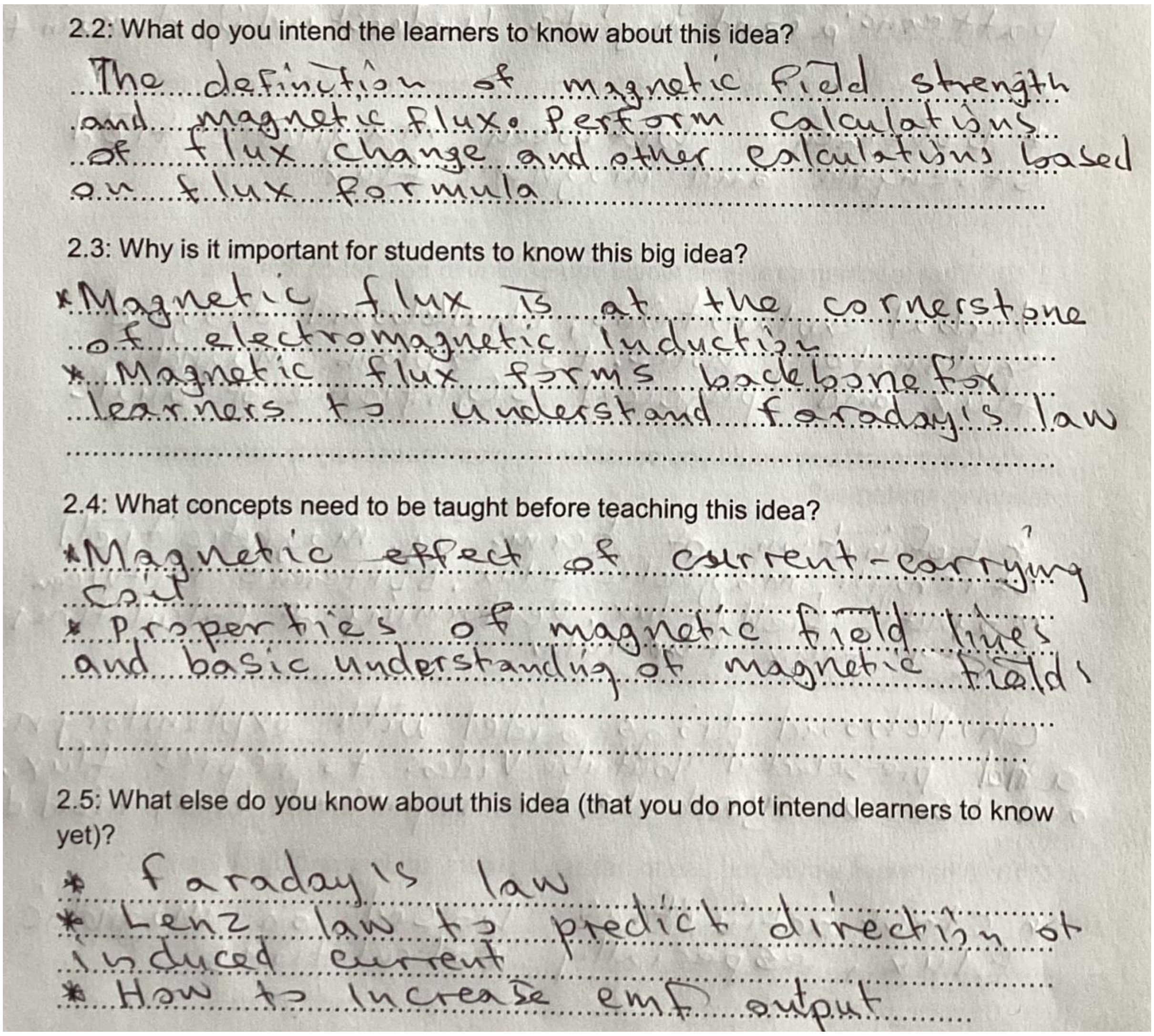
The teacher responded to all the sections of the pre-intervention CoRe. Most of his responses can be attributed to his experience as a Grade 11 Physical Sciences teacher (see Appendix **A3**). Table 4.3.1 shows the result of the scores obtained after a thorough scrutiny of responses. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.3.1: Scores of TE3 based on pre-intervention CoRes in the big ideas of magnetic flux (MF) and Faraday's law (FL).

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency					x	o		
2	Learner understanding			x			o		
3	Conceptual teaching strategies					x	o		
4	Representations			x			o		

4.4.1.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, the teacher mentioned in response to question 2.2 that he intends his learners to know the definition of magnetic field strength, definition of magnetic flux and calculate a change in magnetic flux. Furthermore, the teacher mentioned calculations based on the magnetic flux formula as part of his response to question 2.2. While responding to question 2.3, the teacher cited magnetic flux as the primary concept which underpins the whole idea of electromagnetic induction. He mentioned that understanding the magnetic flux is a prerequisite needed for learners to understand Faraday's law. In his response to question 2.4, the teacher mentioned magnetic effect of a coil carrying current and properties of field lines as concepts to be addressed prior to teaching the big idea of MF. In response to question 2.5, he mentioned Faraday's law and Lenz's law as content yet to be learned by his learners. Figure 4.3.1 shows the teacher's responses to questions 2.2 to 2.5 under CS of the first big idea of MF.



2.2: What do you intend the learners to know about this idea?

The definition of magnetic field strength and magnetic flux. Perform calculations of flux change and other calculations based on flux formula

2.3: Why is it important for students to know this big idea?

*Magnetic flux is at the cornerstone of electromagnetic induction
* Magnetic flux forms backbone for learners to understand faraday's law

2.4: What concepts need to be taught before teaching this idea?

*Magnetic effect of current-carrying coil
* Properties of magnetic field lines and basic understanding of magnetic fields

2.5: What else do you know about this idea (that you do not intend learners to know yet)?

* faraday's law
* Lenz law to predict direction of induced current
* How to increase emf output

Figure 4.3.1 Snapshot of TE3's pre-CoRe responses to CS based on the big idea of MF. Source: Researcher's own.

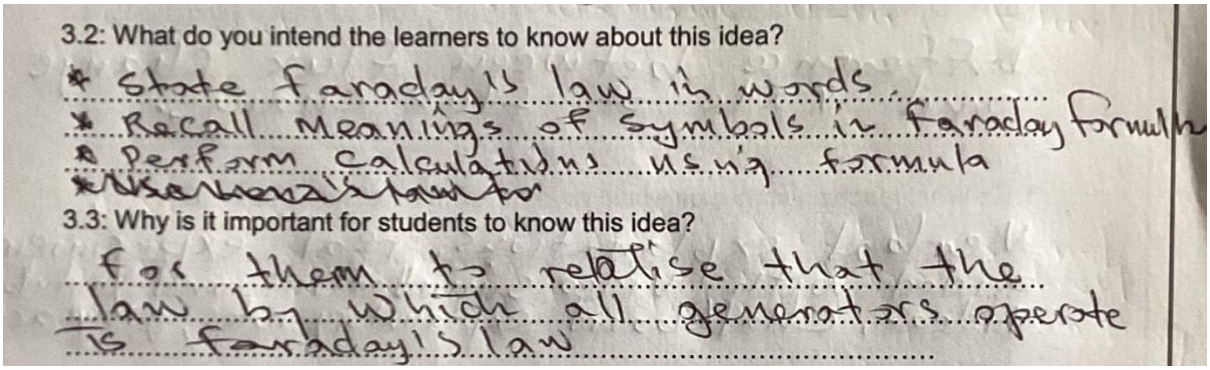
However, saying that magnetic flux is a prerequisite needed for learners to understand Faraday's law was incomplete. It was imperative to mention the change in magnetic flux as a prerequisite in understanding Faraday's law. The teacher's pPCK for this component prior to intervention based on the big idea MF was therefore scored as '*developing*'. This is because 'content knowledge is evident, and there is evidence of knowledge about sequencing and scaffolding of concepts', as stated by the rubric.

For the second big idea of FL, the teacher while responding to question 3.2, mentioned that he wanted his learners to be able to:

- state Faraday's law in words,
- recall the physical meaning of each symbol in Faraday's formula of electromagnetic induction and,

- perform calculations using the using Faraday's formula.

The reason as why it was so important for learners to know the big idea of FL was presented in response to question 3.3 as to enable them to realise that the law by which all generators operate is based on Faraday's law. Figure 4.3.2 shows the teacher's responses to questions 3.2 to 3.3 under CS of the first big idea of FL.



3.2: What do you intend the learners to know about this idea?

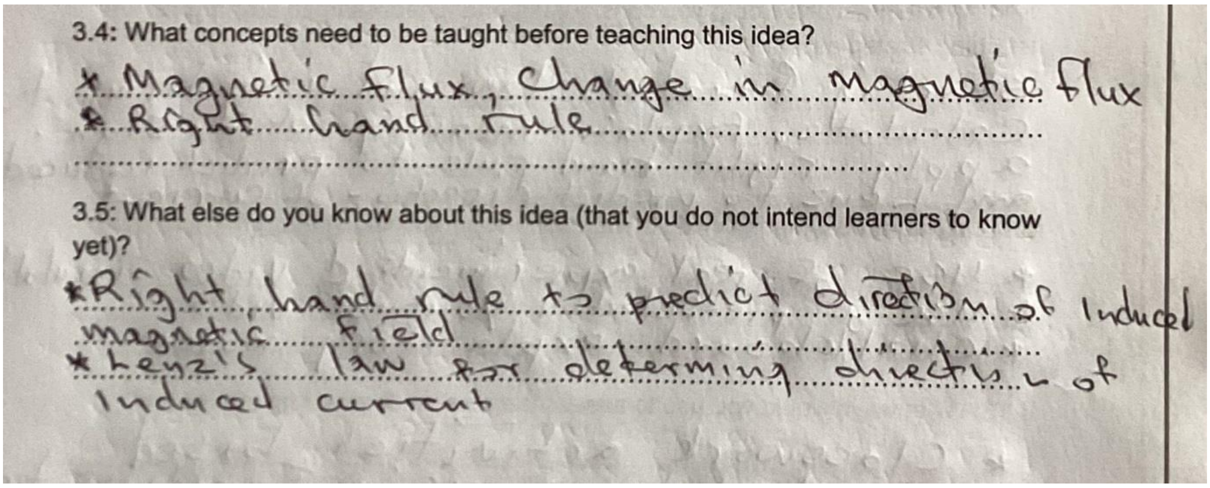
* State Faraday's law in words.
* Recall meanings of symbols in Faraday formula
* Perform calculations using formula
~~*Use Lenz's law for~~

3.3: Why is it important for students to know this idea?

for them to realise that the law by which all generators operate is Faraday's law

Figure 4.3.2: Snapshot of TE3's pre-CoRe responses to CS based on the big idea of FL. Source: Researcher's own.

While responding to question 3.4, the teacher indicated that it was imperative for the learners to be exposed to RHR and magnetic flux and change in magnetic flux prior to being taught Faraday's law. In his response to question 3.5, the teacher further demonstrated the importance of the RHR in predicting the direction of the induced magnetic field and Lenz's law in predicting the direction of the induced current. Figure 4.3.3 shows the teacher's responses to questions 3.4 to 3.5 under CS of the first big idea of FL



3.4: What concepts need to be taught before teaching this idea?

* Magnetic flux, change in magnetic flux
* Right hand rule

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

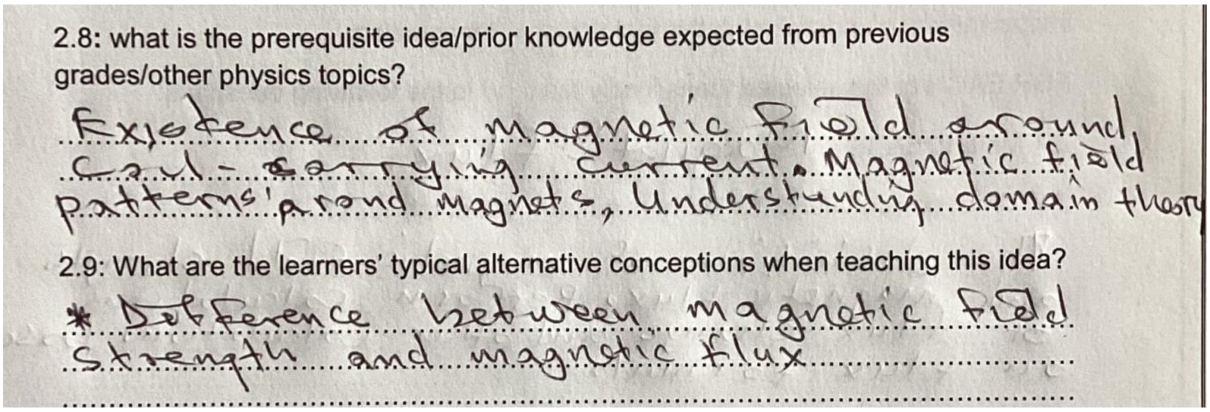
*Right hand rule to predict direction of induced magnetic field
* Lenz's law for determing direction of induced current

Figure 4.3.3: Snapshot of TE3's pre-CoRe responses to CS based on the big idea of FL. Source: Researcher's own.

Hence, the teacher's pPCK for this component based on the two big ideas of FL prior to intervention were scored as '*developing*'. The reason to justify the score is based on the fact that ‘content knowledge is evident and subordinate ideas that account for the application of equations and definitions were identified’, as stated by the scoring rubric. Furthermore, from the teacher’s responses based on questions 2.3 and 2.4 and questions 3.4 and 3.5, the ‘identified pre-concepts consist of those required to understand the current key idea and content knowledge is evident’, as stated by the rubric. However, it is not evident that the ‘selected ideas indicate strategic thinking about content’ as stated in the rubric.

4.4.1.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the existence of magnetic field around a coil carrying current was cited as learners’ prior knowledge for the big idea of magnetic flux. The magnetic field patterns due to field lines around magnets and understanding of the domain theory were quoted as prior knowledge for learners before being exposed to the big idea of MF. The teacher’s responses to questions 2.8 and 2.9 based on the big idea of MF are shown in figure 4.3.4



2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

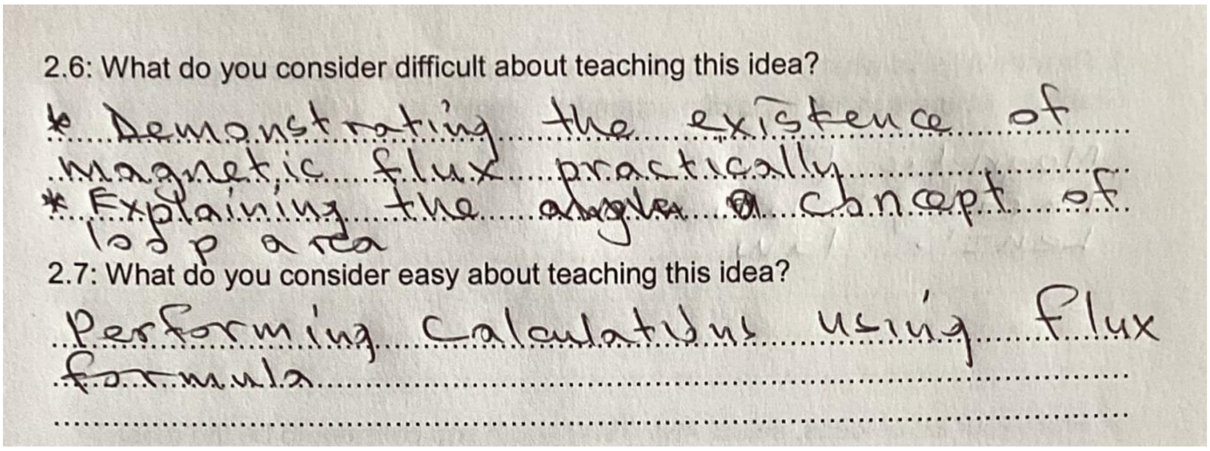
Existence of magnetic field around coil-carrying current. Magnetic field patterns' around magnets, Understanding domain theory

2.9: What are the learners’ typical alternative conceptions when teaching this idea?

* Difference between magnetic field strength and magnetic flux

Figure 4.3.4 Snapshot of TE3’s pre-CoRe responses regarding *learner understanding* for the big idea of MF. Source: Researcher’s own.

The teacher mentioned in figure 4.3.5 that it was difficult to teach and practically demonstrate the existence of magnetic flux. The teacher’s responses to questions 2.6 and 2.7 based on the big idea of MF are shown in figure 4.3.5.



2.6: What do you consider difficult about teaching this idea?

* Demonstrating the existence of magnetic flux practically
* Explaining the ~~angle~~ ~~a~~ concept of loop area

2.7: What do you consider easy about teaching this idea?

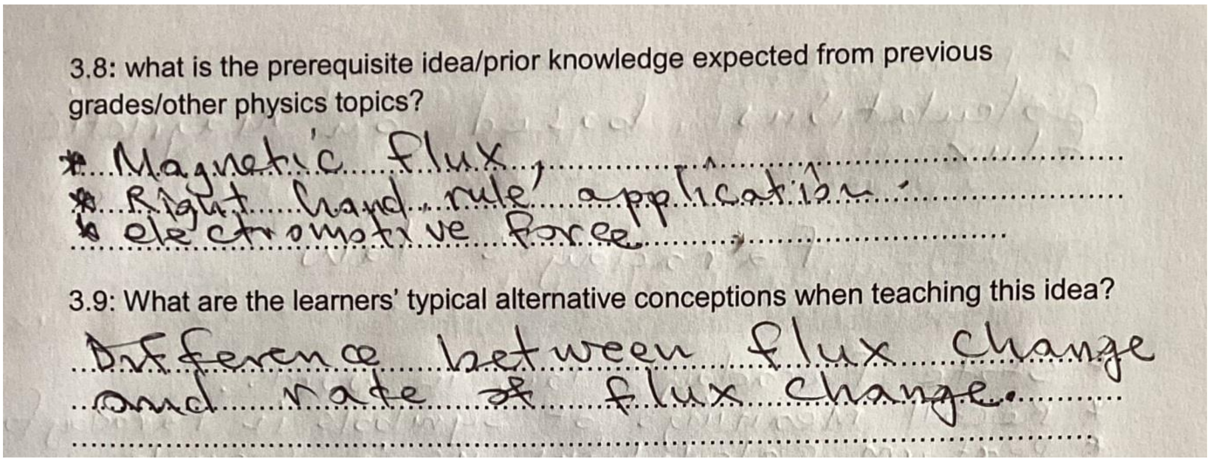
Performing calculations using flux formula

Figure 4.3.5 Snapshot of TE3's pre-CoRe responses based on *learner understanding* big idea of MF. Source: Researcher's own.

However, the teacher did not mention whether the physical significance of the angle in flux formula or calculation of it was easy or difficulty to teach.

Teacher TE4's personal PCK for this component prior to intervention for the big idea MF was scored as '*adequate*'. This is because 'an appropriate difficulty related to only the main ideas is identified and clearly formulated', as stated by the rubric.

For the second big idea of FL, magnetic flux, application of RHR and definition of EMF were cited as prerequisites for learners to understand Faraday's law. However, the teacher made no mention regarding flux change and relative motion since they are important when focusing on Faraday's law. On the other hand, the difference between flux change and rate of flux change was mentioned as another potential source of alternative conceptions amongst the learners. The teacher's responses to questions 3.8 and 3.9 based on the big idea of FL are shown in figure 4.3.6



3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

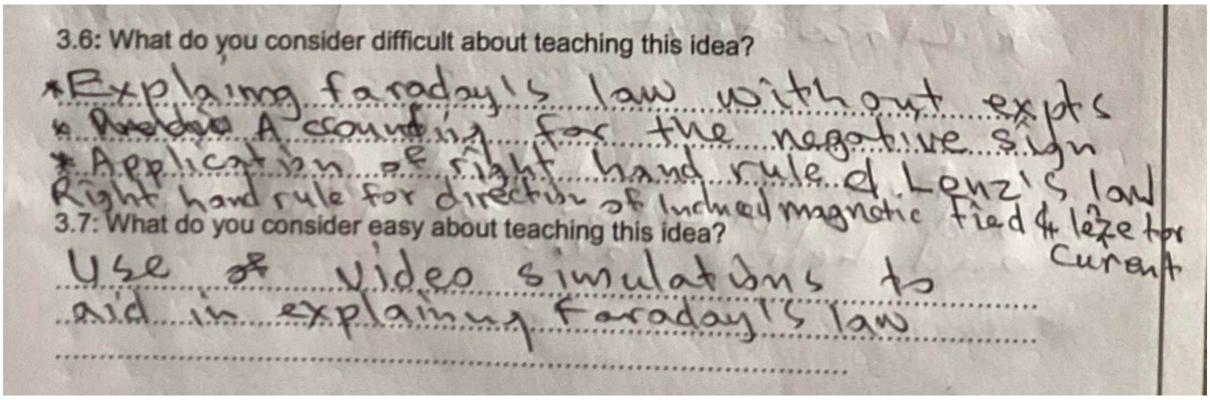
* Magnetic flux,
* Right hand rule application.
* electromotive force.

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Difference between flux change and rate of flux change.

Figure 4.3.6 Snapshot of TE3's pre-CoRe responses regarding *learner understanding* for the big idea of FL. Source: Researcher's own.

Explaining Faraday’s law without the involvement of a real experiment or using computer simulation was mentioned as difficult to teach. Predicting the direction of the induced current to account for the negative sign in Faraday’s formula was mentioned as difficult. Furthermore, the explanation associated with the application of the RHR to determine the direction of the induced magnetic field and Lenz’s law to predict the direction of induced current was mentioned as a difficult part to teach. The use of computer video simulations to demonstrate induction was mentioned as something which makes it easier to teach the second big idea of FL. The teacher’s responses to questions 3.6 and 3.7 based on the big idea of FL are shown in figure 4.3.7



3.6: What do you consider difficult about teaching this idea?

*Explaing faraday's law without expts
* A counting for the negative sign
*Application of right hand rule & Lenz's law
Right hand rule for direction of Induced magnetic fied & leze for Curent

3.7: What do you consider easy about teaching this idea?

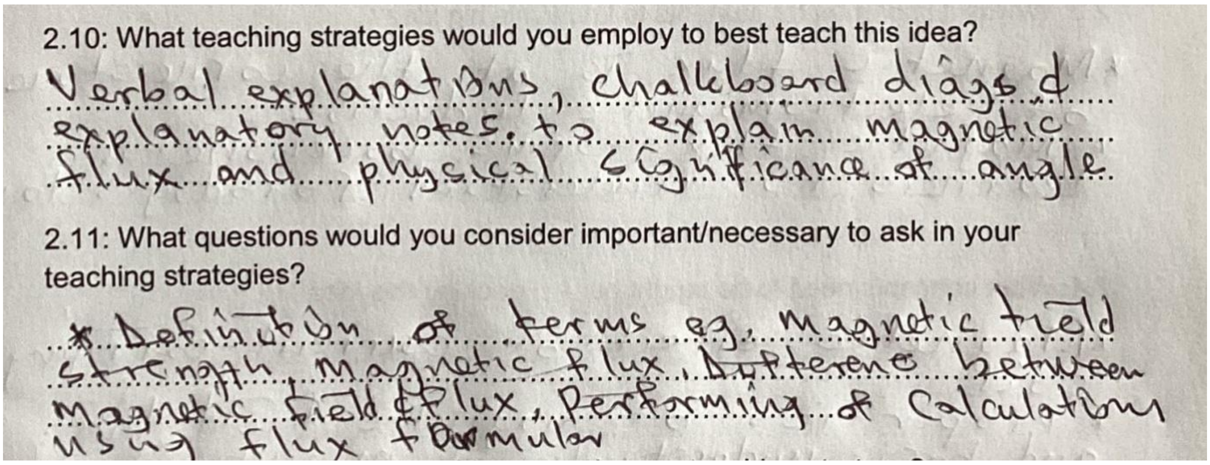
Use of video simulations to
aid in explaining Faraday's law

Figure 4.3.7 Snapshot of TE3’s pre-CoRe responses based on *learner understanding* big idea of FL. Source: Researcher’s own.

Consequently, the teacher’s PCK in this component is scored as ‘*developing*’. This is because ‘appropriate difficulties for two of the main ideas are identified and clearly formulated’, as stated by the rubric.

4.4.1.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, the teacher suggested to employ the use of verbal explanations, chalkboard diagrams with explanatory notes as CTS to illustrate magnetic flux as well as explaining the physical significance of the angle which appears in the flux formula. In response to question 2.11, the teacher suggested asking some guiding questions centred on definition of terms like magnetic field strength and magnetic flux. Furthermore, the teacher suggested asking questions based on the difference between magnetic flux and magnetic field strength, and questions based on performing calculations using magnetic flux formula. The teacher’s responses to questions 2.10 and 2.11 based on the big idea of FL are shown in figure 4.3.8.



2.10: What teaching strategies would you employ to best teach this idea?

Verbal explanations, chalkboard diags & explanatory notes. to explain magnetic flux and physical significance of angle

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

* Definition of terms eg. magnetic field strength, magnetic flux, Difference between magnetic field & flux, Performing of calculations using flux formula

Figure 4.3.8 Snapshot of TE3's pre-CoRe responses regarding his CTS for the big idea of MF. Source: Researcher's own.

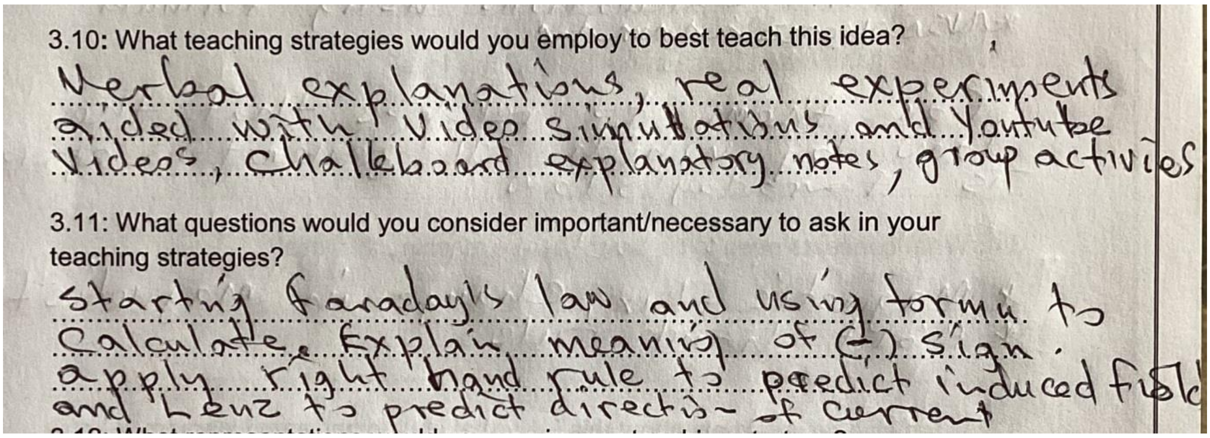
No practical demonstration or computer simulations are mentioned as part of CTS based on the big idea of MF.

The teacher's pPCK for this component based on the first big idea of MF prior to intervention was therefore scored as '*developing*'. This score is justified by the fact that the 'overall strategy is workable and at least two different levels of representation to enforce an aspect or concept with explanatory notes are suggested', as stated by the rubric.

For the second big idea of FL, the teacher mentioned in response to question 3.10, the use of real experiments aided by computer simulations and pre-selected YouTube videos as part of his CTS to be employed when teaching the big idea of FL to his learners. Furthermore, chalkboard explanatory notes and, group activities based on calculations using Faraday's formula were suggested as part of his CTS when teaching Faraday's law.

In response to question 3.11, the teacher proposed asking guiding questions based on stating Faraday's law of electromagnetic induction, use of Faraday's formula to perform some calculations, to explain the physical significance of the negative sign in Faraday's formula. Furthermore, the teacher suggested asking questions based on the application of the RHR to predict the direction of induced magnetic field and Lenz's law to determine direction of induced current.

The teacher's responses to questions 3.10 and 3.11 based on the big idea of FL are shown in figure 4.3.9



3.10: What teaching strategies would you employ to best teach this idea?

Verbal explanations, real experiments aided with video simulations and Youtube videos, chalkboard explanatory notes, group activies

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

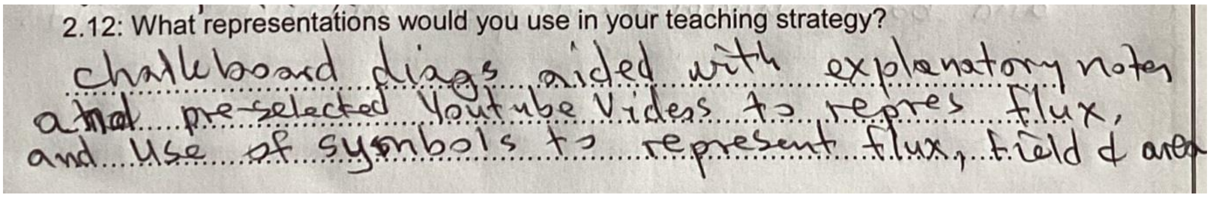
starting Faraday's law and using formu to calculate, Explain meaning of (-) sign. apply right hand rule to predict induced field and Lenz to predict direction of current

Figure 4.3.9 Snapshot of TE3's pre-CoRe responses regarding his CTS for the big idea of FL. Source: Researcher's own.

However, the teacher made no mention of relative motion between coil and magnet. Relative motion underpins Faraday's law of electromagnetic induction. The teacher's pPCK for this component based on the second big idea prior to intervention was therefore scored as '*developing*'. This score is justified by the fact that 'at least two different levels of representation to enforce an aspect or concept with explanatory notes are suggested', as stated by the rubric.

4.4.1.4 REPRESENTATIONS

For the first big idea of MF, the teacher proposes to use chalkboard diagrams aided by explanatory notes and pre-selected YouTube videos for representing magnetic flux and physical significance of the angle. The teacher proposed using mathematical symbols as representations to explain the formula of magnetic flux. Figure 4.3.10 shows the teacher's responses for question 2.12.



2.12: What representations would you use in your teaching strategy?

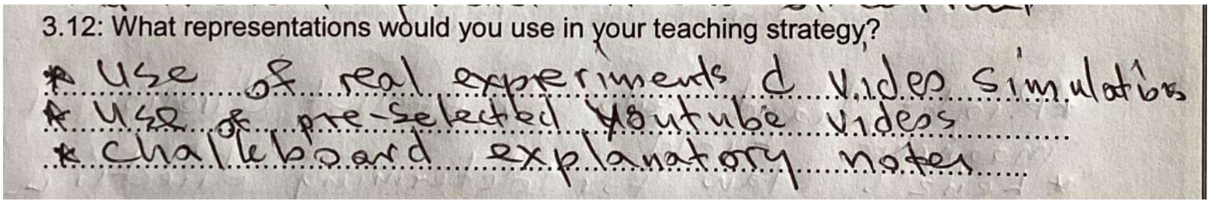
chalkboard diags aided with explanatory notes and pre-selected Youtube Videos to repres flux, and use of symbols to represent flux, field & area

Figure 4.3.10: Snapshot of TE3's pre-CoRe responses regarding his representations for MF. Source: Researcher's own.

However, no practical demonstration or computer simulations are mentioned as other representations to teach the concept of magnetic flux.

The teacher's pPCK for this component based on the first big idea of MF prior to intervention was therefore scored as '*adequate*'. This score is justified by the fact that 'an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts is presented' as stated by the rubric.

For the second big idea of FL, the teacher suggests representations of using real experiments aided by computer simulations and pre-selected YouTube videos. Furthermore, chalkboard explanatory notes are suggested as representations. Figure 4.3.11 shows teacher's responses for question 3.12



3.12: What representations would you use in your teaching strategy?

* Use of real experiments & video simulations
* Use of pre-selected youtube videos
* Chalkboard explanatory notes

Figure 4.3.11: Snapshot of TE3's pre-CoRe responses regarding his representations for FL. Source: Researcher's own.

The teacher's pPCK for this component prior to intervention was scored as '*developing*' because 'some evidence is given of the use of representations to support conceptual development ', as stated in the rubric.

4.4.2 DISCUSSION OF POST-INTERVENTION CoRes

Table 4.3.2 shows the score results obtained after a thorough scrutiny of responses given in TE3's completed post-intervention CoRe based on Grade 11's EMI section of electromagnetism (see Appendix C3). Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

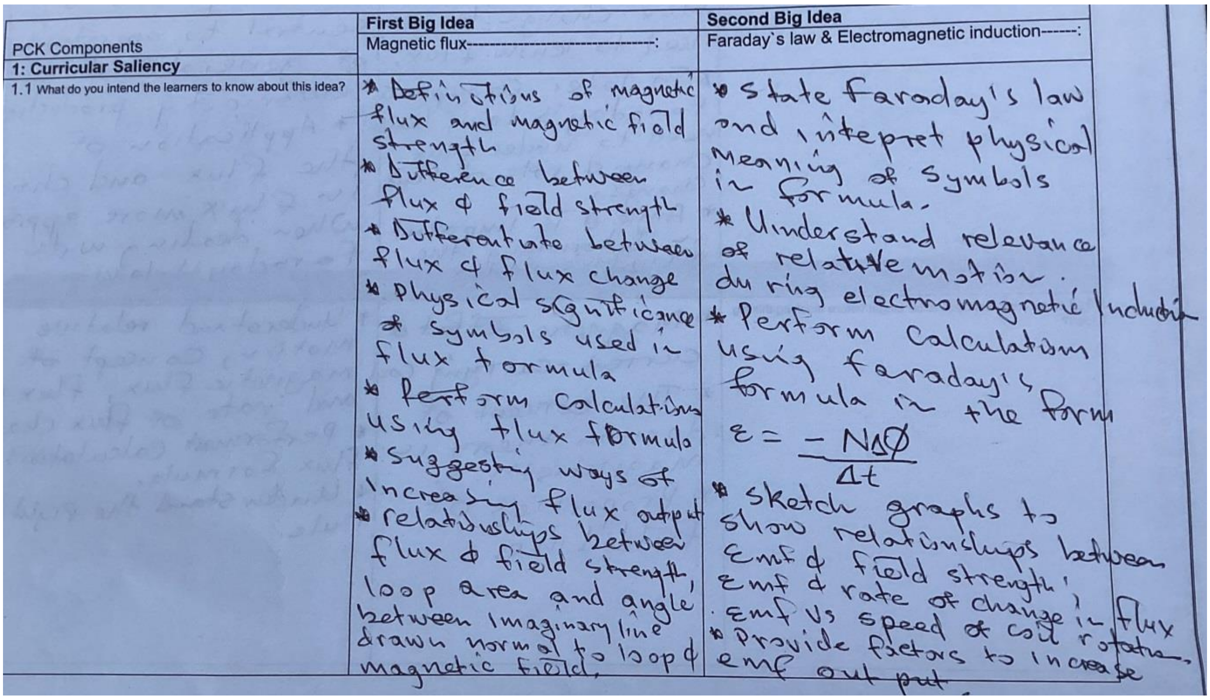
Table 4.3.2: Scores for TE3 based on post-intervention CoRes.

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency							x	o
2	Knowledge of learner understanding					x	o		
3	Conceptual teaching strategies						o	x	
4	Representations							x	o

4.4.2.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, while responding to question 1.1 shown in figure 4.3.12, the teacher suggested stating Faraday's law, symbol interpretation. numerical calculations, RHR application and EMF optimisation as part of CS.

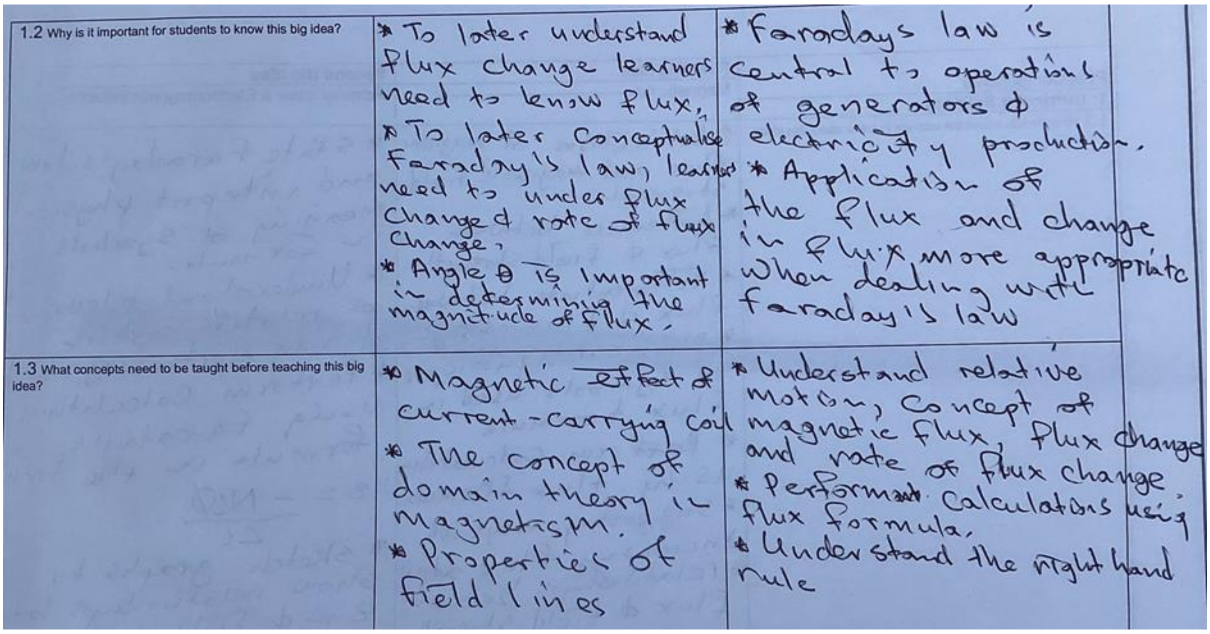
The teacher went further to suggest the importance for his learners to understand the relationships between magnetic flux and other physical variables such as magnetic field strength, cross-sectional area of the loop, and angle between the imaginary line drawn normal to the loop and the magnetic field.



PCK Components	First Big Idea Magnetic flux---------------------------------:	Second Big Idea Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	* Definitions of magnetic flux and magnetic field strength * Difference between flux & field strength * Differentiate between flux & flux change * physical significance of symbols used in flux formula * Perform Calculations using flux formula * Suggesting ways of increasing flux output * relationships between flux & field strength, loop area and angle between imaginary line drawn normal to loop & magnetic field.	* State Faraday's law and intepret physical Meaning of Symbols in formula. * Understand relevance of relative motion during electromagnetic Induction * Perform Calculations using faraday's formula in the form $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ * sketch graphs to show relationships between emf & field strength; emf & rate of change in flux; emf vs speed of coil rotation. * Provide factors to increase emf out put

Figure 4.3.12: Snapshot of TE3’s post-CoRe responses to question 1.1 regarding CS for MF (left) and FL (right). Source: Researcher’s own.

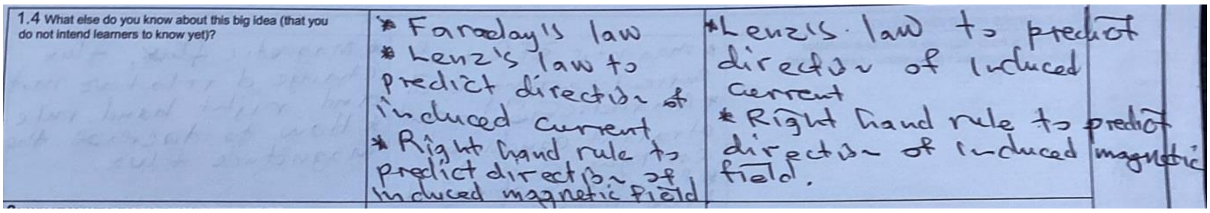
In his response to question 1.2, shown in figure 4.3.13, the teacher indicated the importance of the big idea of magnetic flux in flux change, rate of flux change and ultimately in Faraday’s law. Furthermore, the teacher cited the significance of angle θ as one of the primary determinants of magnitude of the magnetic flux. While responding to question 1.3, shown in figure 4.3.13, the teacher pointed out that it was imperative for learners to be exposed to the magnetic effect of current-carrying coil as well as to the concept of the domain theory.



1.2 Why is it important for students to know this big idea?	* To later understand flux change learners need to know flux, * To later conceptualise Faraday's law, learners need to under flux change & rate of flux change, * Angle θ is important in determining the magnitude of flux.	* Faradays law is central to operations of generators & electricity production. * Application of the flux and change in flux more appropriate when dealing with faraday's law	
1.3 What concepts need to be taught before teaching this big idea?	* Magnetic effect of current-carrying coil * The concept of domain theory in magnetism. * Properties of field lines	* Understand relative motion, concept of magnetic flux, flux change and rate of flux change. * Performant calculations using flux formula. * Understand the right hand rule	

Figure 4.3.13 Snapshot of TE3's post-CoRe responses to question 1.2 and 1.3 regarding CS for MF (left) and FL (right). Source: Researcher's own.

In his response to question 1.4 shown in figure 4.3.14, the teacher mentioned Faraday's law, Lenz's law and application of the RHR to determine the direction of the induced current.



1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	* Faraday's law * Lenz's law to predict direction of induced current * Right hand rule to predict direction of induced magnetic field	* Lenz's law to predict direction of induced current * Right hand rule to predict direction of induced magnetic field.	

Figure 4.3.14: Snapshot of TE3's post-CoRe responses to question 1.4 regarding CS for MF (left) and FL (right). Source: Researcher's own.

The teacher's pPCK for this component based on the first big idea of MF after the intervention was therefore scored as '*exemplary*'. This score is justified by the fact that 'there are indications that attention was paid to the sequencing of the ideas and the subordinate ideas that account for the application of equations and definitions are identified', as stated by the rubric.

While the teacher was responding to question 1.1, based on the second big idea of FL, the teacher presented the following as content knowledge intended for learners as recipients:

- state Faraday's law and interpret the physical meaning of each symbol.
- understand the relevance of relative motion between coil and magnet during induction of EMF in line with big idea of FL, and
- provide factors necessary to optimise EMF signal output.

The teacher's detailed response to question 1.1, based on the second big idea of FL, are presented in figure 4.3.12.

In his response to question 1.2, shown in figure 4.3.13, the teacher mentioned that the application of flux and change in flux were more appropriate when dealing with Faraday's law. The teacher mentioned that Faraday's law was central to the operations of generators and electricity production.

In response to question 1.3, shown in figure 4.3.13, magnetic flux, flux change and the RHR were cited as concepts which needed to be taught before introducing FL. Relative motion was another necessary concept to be taught to learners before being introduced to the concept of FL. Furthermore, he mentioned that his learners needed to be able to:

- Understand the physical significance of rate of flux change during EMF induction.
- Use formula to perform some calculations.

The teacher mentioned in his response to question 1.4 that Lenz's law was necessary to predict the direction of induced current. Furthermore, the RHR was to be applied to predict the direction of the induced magnetic field in conjunction with Lenz's law to determine the direction of the induced current.

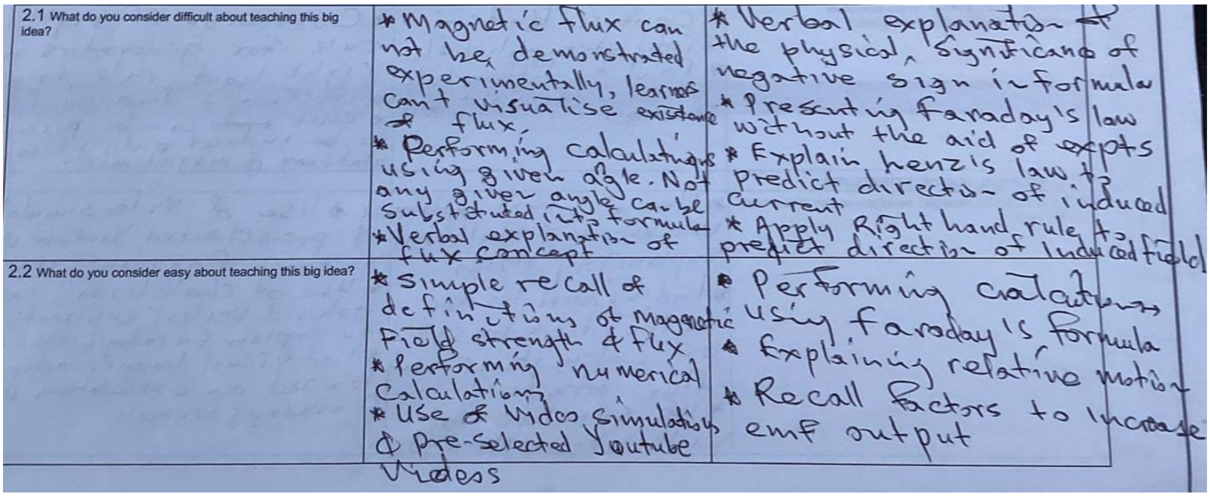
The teacher's pPCK for this component based on the second big idea of FL after the intervention was therefore scored as '*exemplary*'. This score is justified by the fact that 'there is evidence of appropriate sequencing of ideas and the subordinate ideas constitute an exhaustive list of concepts to be taught', as stated by the rubric. Furthermore, the identified pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the second big idea of FL.

4.4.2.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the teacher indicated that the use of real experiments to teach magnetic flux was difficult as learners cannot easily visualise the existence of magnetic flux.

Furthermore, the teacher reveals his knowledge of learners' challenges when he mentioned that the tricky part when performing calculations using the flux formula involves the angle.TE3 indicated that not every given angle can be directly substituted into the flux formula. Explaining the concept of magnetic flux verbally was captured as difficult for learners to understand.

He regards recalling definitions and performing general numerical calculations as easy as shown in figure 4.3.15.

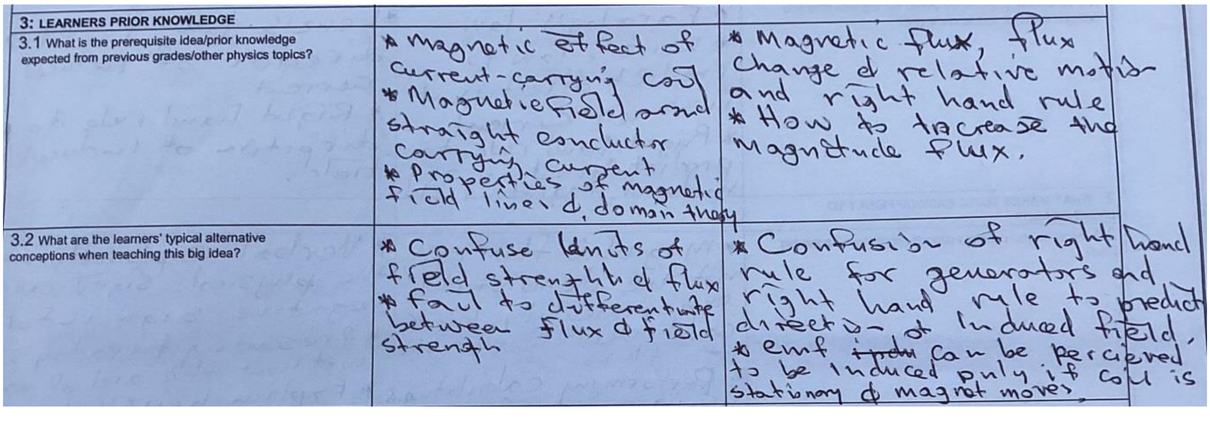


2.1 What do you consider difficult about teaching this big idea?	* Magnetic flux can not be demonstrated experimentally, learners can't visualise existence of flux, * Performing calculations using given angle. Not any given angle can be substituted into formula * Verbal explanation of flux concept	* Verbal explanation of the physical significance of negative sign in formula * Presenting Faraday's law without the aid of expts * Explain Lenz's law to predict direction of induced current * Apply Right hand rule to predict direction of induced field
2.2 What do you consider easy about teaching this big idea?	* Simple recall of definitions of magnetic field strength & flux * Performing numerical calculations * Use of video simulations & pre-selected Youtube videos	* Performing calculations using Faraday's formula * Explaining relative motion * Recall factors to increase emf output

Figure 4.3.15: Snapshot of TE3’s post-CoRe responses regarding learner understanding for MF (left) and FL (right). Source: Researcher’s own.

In response to question 3.1 shown in figure 4.3.16, the teacher cited the magnetic effect of a current-carrying coil, the magnetic field around a straight conductor carrying current and the properties of magnetic field lines as prior knowledge needed before teaching magnetic flux.

While responding to question 3.2 based on the first big idea of MF, shown in figure 4.3.16, the teacher indicated that the learners were likely to confuse the SI units of the magnetic field strength with those of the magnetic flux and were likely to view magnetic field strength and magnetic flux as one and the same thing.



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	* Magnetic effect of current-carrying coil * Magnetic field around straight conductor carrying current * Properties of magnetic field lines & domain theory	* Magnetic flux, flux change & relative motion and right hand rule * How to increase the magnitude flux.
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	* Confuse units of field strength & flux * fail to differentiate between flux & field strength	* Confusion of right hand rule for generators and right hand rule to predict direction of induced field. * emf ~~indu~~ can be perceived to be induced only if coil is stationary & magnet moves.

Figure 4.3.16 Snapshot of TE3’s post-CoRe responses regarding learner understanding for MF (left) and FL (right). Source: Researcher’s own.

The teacher’s pPCK for this component based on the second big idea after the intervention was therefore scored as ‘*developing*’. This score is justified by the fact that ‘appropriate difficulties for two of the main ideas are identified and clearly formulated' as stated in the rubric.

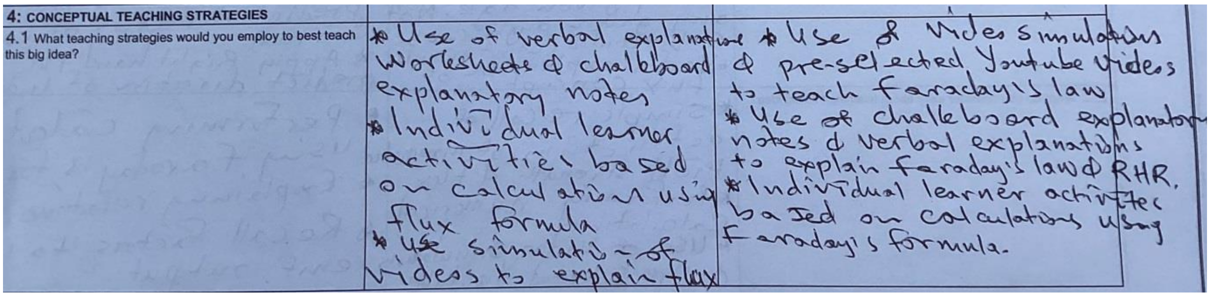
For the second big idea of FL, shown in figure 4.3.15, the teacher pointed out that trying to convince learners by verbally explaining the physical significance of the negative sign in the formula without real experiments or some virtual experiments was difficult. The application of the RHR to predict the direction of the induced magnetic field was mentioned as difficult when teaching. Furthermore, teaching how Lenz's law is applied in predicting the direction of current without conducting real experiments was mentioned as not easy. In response to question 2.2, performing some calculations using Faraday's formula and explaining the physics of relative motion between coil and magnet was mentioned as easy to teach.

The teacher mentioned while responding to question 3.1, that magnetic flux, magnetic flux change, physical implications of relative motion and application of RHR as the necessary knowledge needed by learners prior to their being exposed to Faraday's law. In his response to question 3.2 based on the second big idea of FL shown in figure 4.3.16, the teacher cited the RHR for generators as a possible confusion; this may only become a problem later as generators are taught in Grade 12. Furthermore, the teacher mentioned that some learners might consider EMF induction as a phenomenon which occurs only if it is the magnet making movement into and out of the coil.

The teacher's pPCK for this component based on the second big idea of FL after the intervention was therefore scored as '*developing*'. This is because 'appropriate difficulties for two of the main ideas are identified and clearly formulated', as stated in the rubric.

4.4.2.3 CONCEPTUAL TEACHING STRATEGIES

In his response to question 4.1, shown in figure 4.3.17, based on the first big idea of MF, verbal explanations, worksheets, and chalkboard diagrams with explanatory notes, simulations and videos were suggested as part of CTS to aid learners' understanding of magnetic flux. The teacher suggested some individual activities based on calculations to enable learners to independently solve problems.



4: CONCEPTUAL TEACHING STRATEGIES		
4.1 What teaching strategies would you employ to best teach this big idea?	* Use of verbal explanations Worksheets & chalkboard explanatory notes * Individual learner activities based on calculation using flux formula * Use simulation of videos to explain flux	* Use of videos simulations & pre-selected Youtube videos to teach Faraday's law * Use of chalkboard explanatory notes & verbal explanations to explain Faraday's law & RHR. * Individual learner activities based on calculations using Faraday's formula.

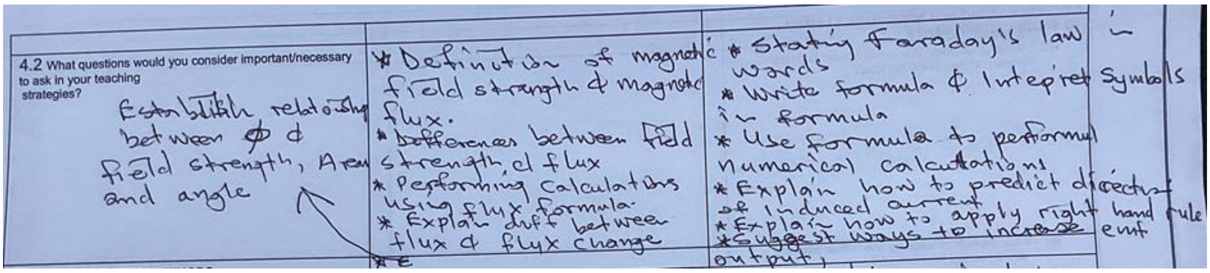
Figure 4.3.17: Snapshot of TE3’s post-CoRe responses to question 4.1 regarding CTS for MF (left) and FL (right). Source: Researcher’s own.

While responding to question 4.2, shown in figure 4.3.18, the teacher suggested guiding questions related to definitions, distinctions and relationships between concepts, and numerical calculations.

The teacher’s pPCK for this component based on the first big idea was therefore scored as ‘*exemplary*’. This is because ‘the suggested strategy is highly learner-centred and there is evidence that the strategy will support conceptual understanding’ as stated in the rubric.

For the second big idea of FL, shown in figure 4.3.17, the teacher proposed to use videos simulations backed with pre-selected YouTube videos as an effective CTS. Furthermore, the teacher suggested to make use of the traditional verbal explanatory approach aided by chalkboard explanatory notes to enable learners to understand Faraday’s law and the RHR’s application. Individual activities based on numerical calculations using Faraday’s formula was suggested as part of CTS necessary for learners to independently solve problems.

While responding to question 4.2, shown in figure 4.3.18, the teacher suggested guiding questions related to stating Faraday’s law, symbol interpretation. numerical calculations, RHR application and EMF optimisation. However, he did not mention Lenz’s law or any opportunities for learners to apply Lenz’s law themselves.



4.2 What questions would you consider important/necessary to ask in your teaching strategies? Establish relationship between Φ & field strength, Area and angle	* Definition of magnetic field strength & magnetic flux. * Differences between field strength & flux * Performing calculations using flux formula * Explain diff between flux & flux change * E	* Stating Faraday's law in words * Write formula & Intepret Symbols in formula * Use formula to perform numerical calculations * Explain how to predict direction of induced current * Explain how to apply right hand rule * Suggest ways to increase emf output,

Figure 4.3.18: Snapshot of TE3’s post-CoRe responses to question 4.2 regarding CTS for MF (left) and FL (right). Source: Researcher’s own.

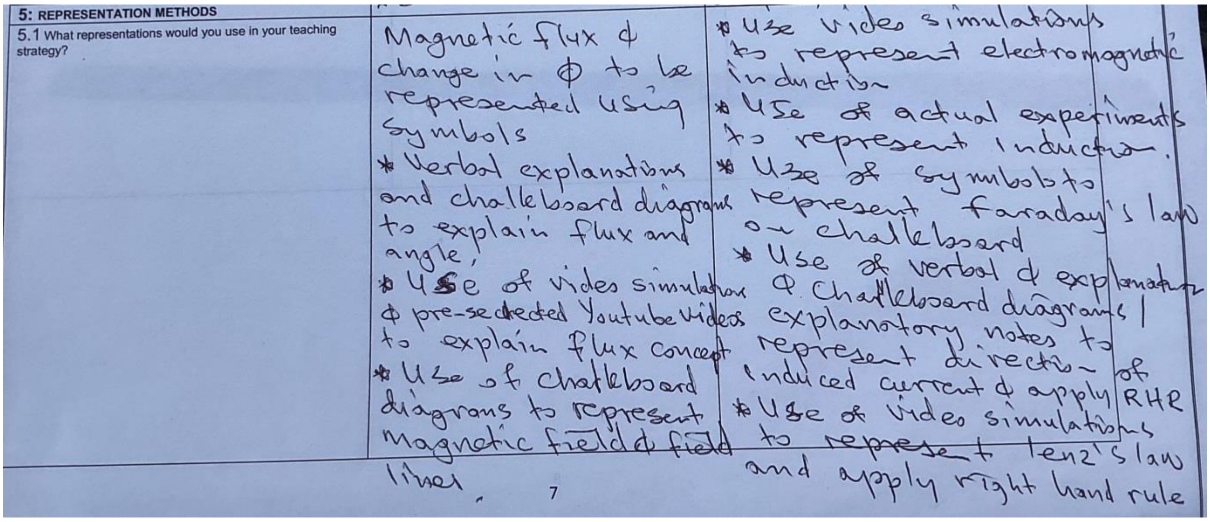
The teacher's pPCK for this component based on the second big idea of FL was scored as '*developing*'. This is because the 'use of macroscopic, visual and symbolic representations to enforce aspect(s) of a concept are given' but 'attention being paid to sequencing for conceptual development is not evident', as suggested in the rubric.

4.4.2.4 REPRESENTATIONS

For the first big idea of MF, shown in figure 4.3.19, the teacher suggested to represent magnetic flux and change in magnetic flux using symbols, chalkboard diagrams, explanatory notes video simulations and pre-selected YouTube videos.

The teacher's pPCK for this component based on the first big idea of MF, was scored as '*exemplary*' after the intervention. This is because 'an adequate selection of representations (visual or symbolic) sufficient to support explanation of concepts is presented', as stated in the rubric.

For the second big idea of FL, shown in figure 4.3.19, the teacher proposed to use the same forms of representation as those suggested for the first big idea of MF.



5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	Magnetic flux & change in Φ to be represented using symbols * Verbal explanations and chalkboard diagrams to explain flux and angle, * Use of video simulations & pre-selected Youtube videos to explain flux concept * Use of chalkboard diagrams to represent magnetic field & field lines	* Use video simulations to represent electromagnetic induction * Use of actual experiments to represent induction. * Use of symbols to represent faraday's law on chalkboard * Use of verbal & explanatory & chalkboard diagrams / explanatory notes to represent direction of induced current & apply RHR * Use of video simulations to represent lenz's law and apply right hand rule

7

Figure 4.3.19: Snapshot of TE3's post-CoRe responses regarding representation for MF (left) and FL (right). Source: Researcher's own.

The teacher's pPCK for this component, based on the second big idea after the intervention was scored as '*exemplary*'. This is because 'extensive use of representations (visual and symbolic / graphical / pictorial / diagrammatic) to enforce specific aspect(s) of concepts being developed are suggested', as stated in the rubric.

4.4.3 COMPARISON OF TE3's PRE- and POST-INTERVENTION CoRes

The scores for each PCK component from tables 4.3.1 and 4.3.2 are compared in order to gain an overall impression of whether the scoring levels have improved following the intervention. Table 4.3.3 shows a summary of these scores.

Table 4.3.3 Summary of TE3's pre- and post-intervention personal PCK scores.

PCK Components	**PCK Scoring level summary**															
	PRE-CoRe								**POST-CoRe**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency					x	o									x	o
Learner understanding			x			o							x	o		
Conceptual teaching strategies					x	o								o	x	
Representations			x			o									x	o

From table 4.3.3, the immediate observation is that the PCK scores shifted from predominantly adequate (A) and developing (D) in the pre-intervention CoRe to predominantly developing (D) and exemplary (E) in post-intervention CoRe. The post-CoRe scores highlighted in yellow shows which scores improved after the intervention compared to pre-CoRe scores. This gives the general impression that the intervention had an impact on the way TE3 constructed his post-intervention CoRes.

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in table 4.1.4. Table 4.3.4 shows the comparative PCK scores on a numerical scale.

Table 4.3.4: Summary of TE3's comparative PCK scores on a scale ranging from 1 to 4.

PCK Components	**Scores**					
	Pre-CoRe			**Post-CoRe**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	3	3	3.0	4	4	4.0
Learner understanding	2	3	2.5	3	3	3.0
Conceptual teaching strategies	3	3	3.0	4	3	3.5
Representations and analogies	2	3	2.5	4	4	4.0
Total (16)	10	12	11.0	15	14	14.5
Average (4)	2.5	3.0	2.8	3.8	3.5	3.6

There was a noticeable difference between pre-CoRe scores and post-CoRe scores based on the big idea of MF. The scores increased by an average of 1.3 points (from a score of 2.5 to 3.8). Furthermore, there was an increase between the pre-CoRe scores and post-CoRe scores that was observed based on the second big idea of FL. The scores increased by an average of 0.5 points (from a score of 3.0 to 3.5) after the intervention. Combining the two big ideas, the overall average score increased by 0.8 points (from 2.8 for pre-CoRe to 3.6 for post-CoRe). This is partial evidence that the intervention had an impact in the way TE3 constructed his CoRes based on EMI prior to teaching it.

4.4.4 VIDEO-RECORDED LESSON OBSERVATIONS: THE CASE OF TE3.

The transcript of the video recorded lesson is available in Appendix D3. Five sections were identified from his video recorded lesson. Having taught the Grade 11 section of electromagnetism for at least five years, he had developed his own pedagogical skills of handling the Grade 11 EMI section. TE3 managed to teach both the first and second big ideas of MF and FL in just one lesson. The entire lesson took approximately 59min 33sec.

Section 1: Introduction revision of knowledge based on the previous lesson. [4min 03sec]

The introductory discussion touched briefly on recapping the activities of the previous lesson based on magnetic effect of a coil-carrying current. In his introduction, the teacher showed his learners a short video based on the EMI section (see figure 4.3.20).

Figure 4.3.20: Screenshot of TE3 introducing electromagnetic induction. Source: Researcher’s own.

The video showed a brief summary of the two big ideas of MF and FL and gave his learners the overall impression of what to expect in the lesson.

Section 2: Teaching the first big idea of MF [16min 25sec]

While introducing the first big idea of magnetic flux the teacher started off by writing the definition of magnetic flux and the flux equation on the chalkboard. He then went on to verbally explain magnetic flux and the physical meaning of each symbol in the flux formula.

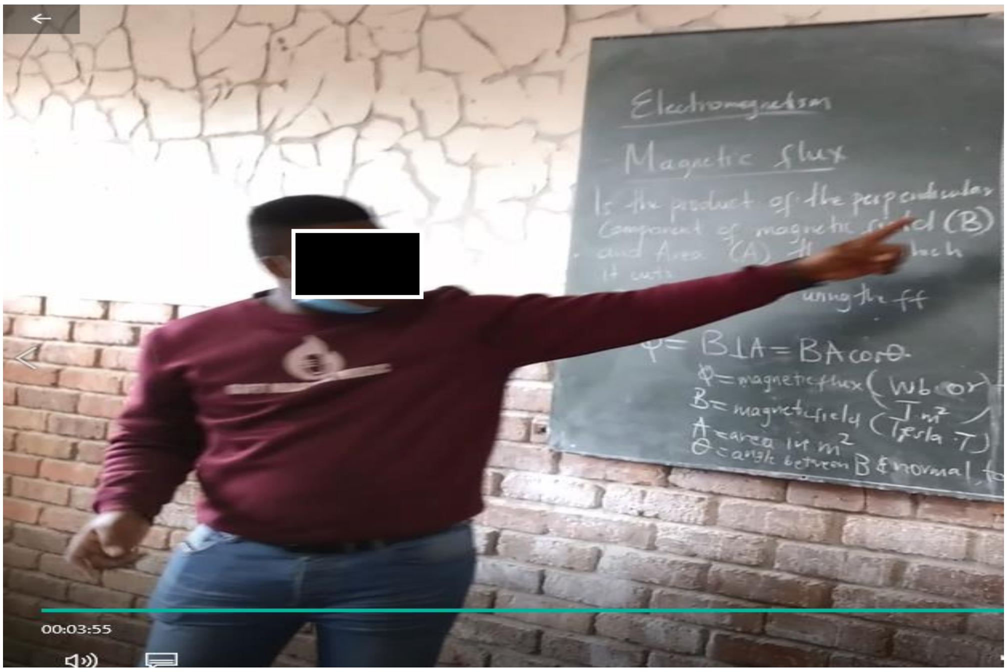

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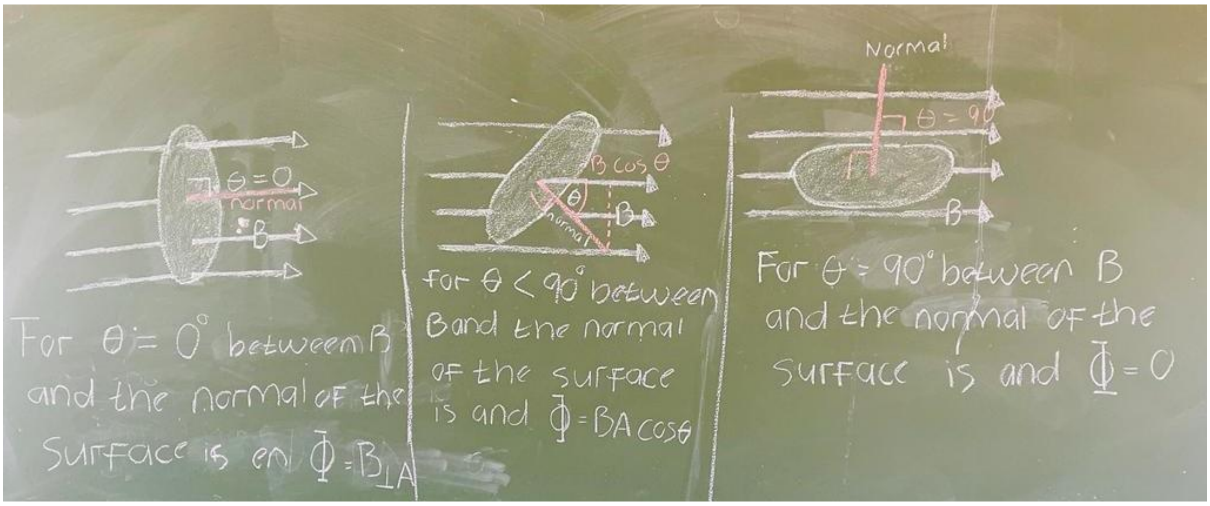
Figure 4.3.21: Screenshot of TE3 presenting the concept of MF. Source: Researcher’s own.

He verbally explained the physical significance of the angleθ in the flux formula, and the difference between magnetic field strength and magnetic flux. His verbal explanations included the change in magnetic flux.

The teacher used chalkboard diagrams shown in figure 4.3.22 while explaining the significance of angle.



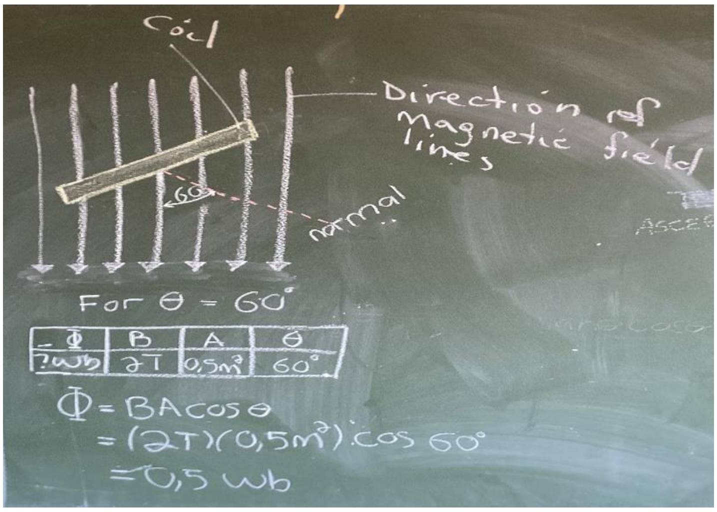
For $\theta = 0^\circ$ between B and the normal of the surface is en $\Phi = B_\perp A$

for $\theta < 90^\circ$ between B and the normal of the surface is and $\Phi = BA\cos\theta$

For $\theta = 90^\circ$ between B and the normal of the surface is and $\Phi = 0$

Figure 4.3.22: Snapshot showing diagrams used to explain angle θ. Source: Researcher’s own.

A worked example shown in figure 4.3.23 was then conducted on the chalkboard to enable learners to use the flux formula. The teacher placed more emphasis on the importance of angle θ during numerical calculations.



For $\theta = 60^\circ$

Φ	B	A	θ
?wb	2T	0,5m²	60°

$$\Phi = BA\cos\theta$$
$$= (2T)(0{,}5m^2)\cdot\cos 60^\circ$$
$$= 0{,}5\ \text{wb}$$

Figure 4.3.23: Snapshot showing diagram used to perform a calculation based on 60^0 angle. Source: Researcher’s own.

He then requested his learners to attempt two questions based on magnetic flux from their textbook. While the learners were busy responding to the questions in their class work books, TE3 moved around monitoring progress and assisting learners with some individual challenges based on MF.

Section 3: Teaching the second big idea of FL [18min 12sec]

TE3 then went on to introduce the concept of electromagnetic induction and Faraday's law while linking it with magnetic flux. In his introduction, he started by showing learners a short video based on Faraday's law of electromagnetic induction.

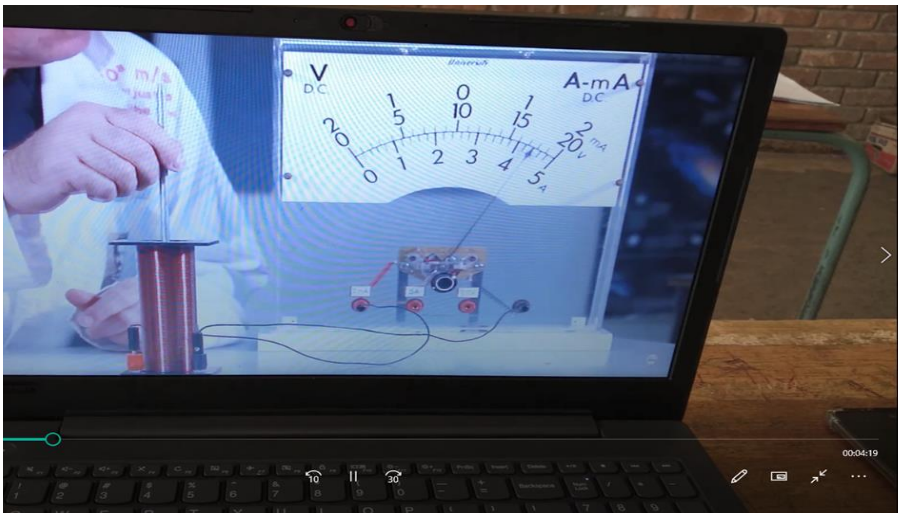


Figure 4.3.24: Screenshot of the video simulation used to introduce Faraday's law. Source: Researcher's own.

The teacher practically demonstrated electromagnetic induction by moving a bar magnet over a coil of copper wire connected to a voltmeter as shown in figure 4.3.25.

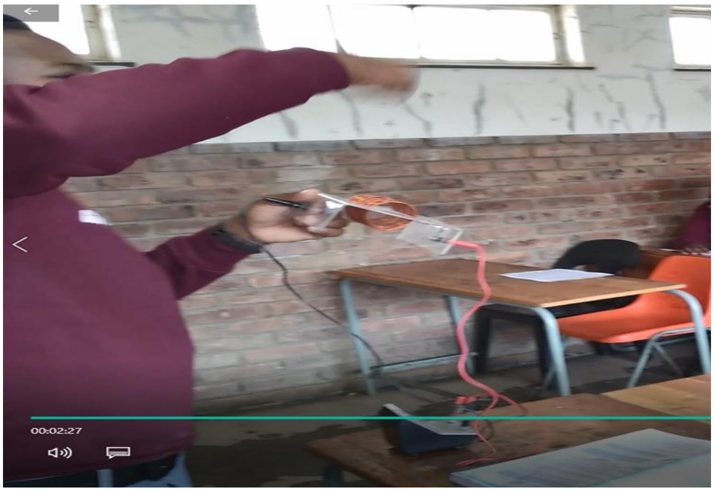


Figure 4.3.25: Screenshot showing teacher trying to demonstrate the induction principle. Source: Researcher's own.

However, no deflection on his voltmeter was noted. He said to his learners:

> *Unfortunately, there is no reading being shown on the voltmeter. I think the magnet is very weak…*

The teacher went on to write Faraday’s law statement as well as the formula on the chalkboard. He then verbally explained and paraphrased Faraday’s law to his learners:

> *In other words, emf can only be induced if and only if there is some sort of relative motion between coil and magnet.*

He also verbally explained the physical significance of each symbol in the formula.

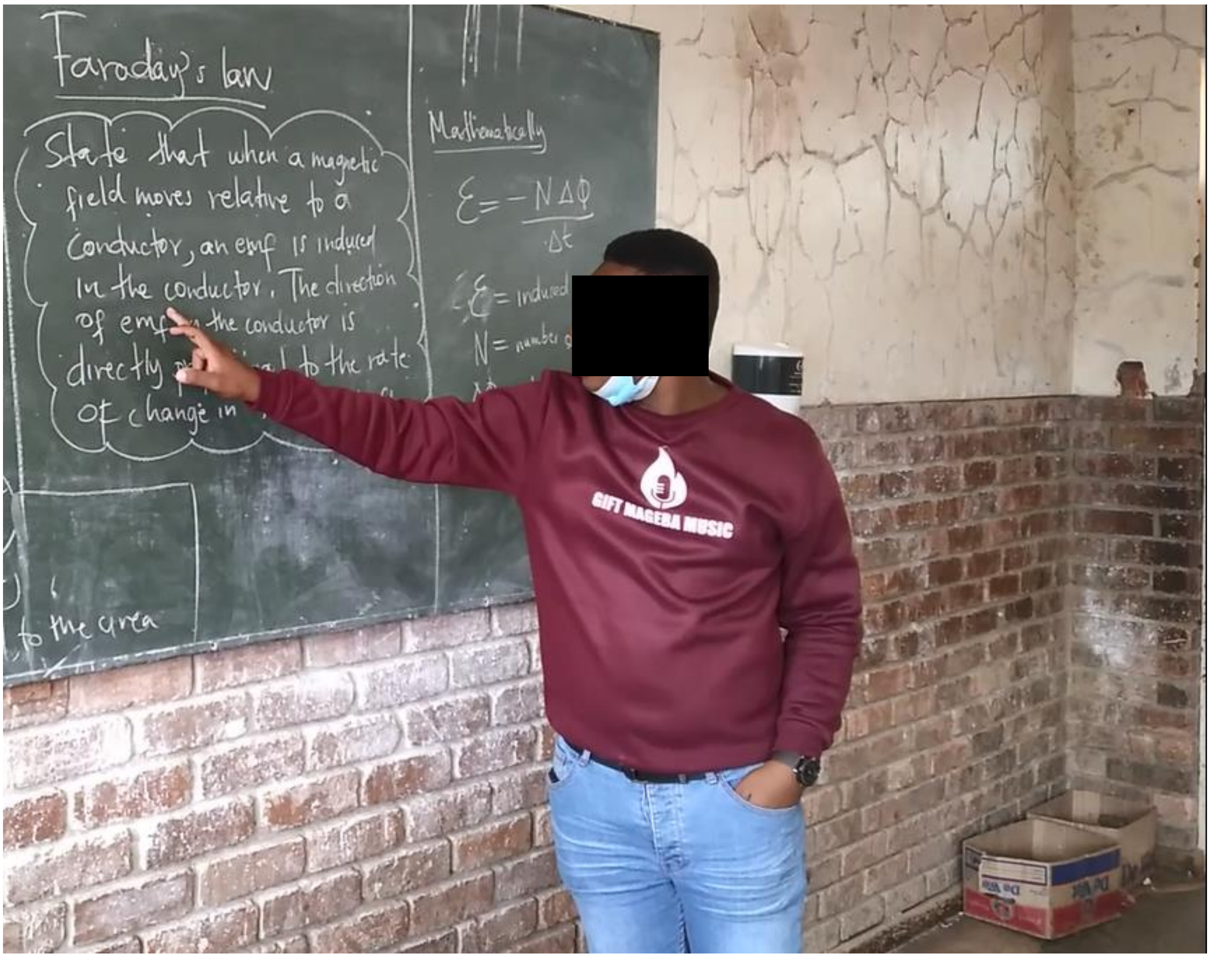

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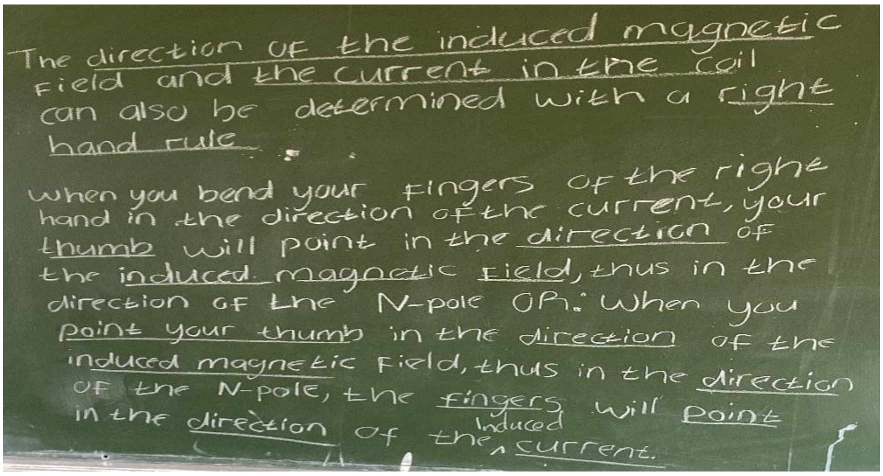
Figure 4.3.26: Screenshot showing TE3 using chalkboard notes to explain Faraday’s law. Source: Researcher’s own.

The teacher explained using chalkboard notes how the RHR is applied to the induced current as shown in 4.3.27.



The direction of the induced magnetic field and the current in the coil can also be determined with a right hand rule.

When you bend your fingers of the right hand in the direction of the current, your thumb will point in the direction of the induced magnetic field, thus in the direction of the N-pole OR: When you point your thumb in the direction of the induced magnetic field, thus in the direction of the N-pole, the fingers will point in the direction of the induced current.

Figure 4.3.27: Snapshot of chalkboard notes used to explain RHR and direction of current. Source: Researcher’s own

However, he does not mention Lenz’s law, so the learners were stuck. They first needed the direction of the induced field before they could find the induced current.

Section 4: Teaching second big idea of FL using video simulations [17min 24sec]

In the video simulation shown in figure 4.3.28, the learners observed a deflection on the galvanometer when a bar magnet moved towards and into the coil.

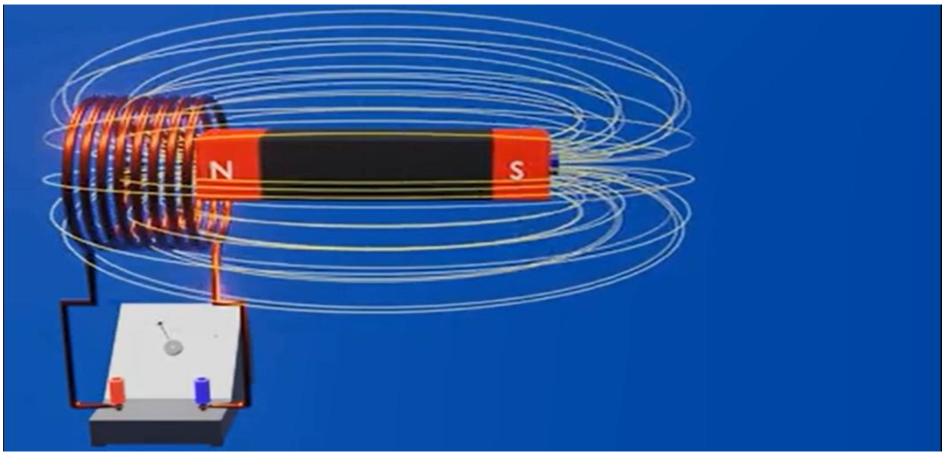


Figure 4.3.28: Screenshot showing induced current due to movement of magnet. Source: Researcher’s own.

The deflection occurred when the magnet was moving towards the coil. When the magnet was held stationary inside the coil, the learners observed that there was no deflection on the galvanometer.

When he asked his learners the reason why the galvanometer reads zero, one of his learners was quick to respond.

> *I think it is because the magnet is no longer moving. But if the magnet keeps on moving inside the coil the galvanometer will give us a reading.*

The teacher further emphasised on the learner's explanation by relative motion. The learners observed that when the bar magnet was pulled out of the coil, there was a deflection on the galvanometer in the opposite direction.

The teacher took this opportunity to re-emphasise on the first big idea of MF saying that:

> *I think you can all observe the white strands of lines around the bar magnet. They represent magnetic field lines. Please note that those field lines passing through the coil during relative motion are representing magnetic flux. The more field lines we have passing through the coil, the greater the magnetic flux.*

During the simulated videos, a question was raised by a learner:

> *So, does it mean that the induced current only due to relative motion between coil and magnet?*

The teacher's response was:

> *No, not necessarily coil and magnet in relative motion. Even a current-carrying coil can give rise to a change in magnetic flux.*

The teacher used another video simulation, shown in figure 4.3.29, to further explain how current is induced. In his explanation, he emphasised that it was not only a magnet that gives rise to a change in magnetic flux.

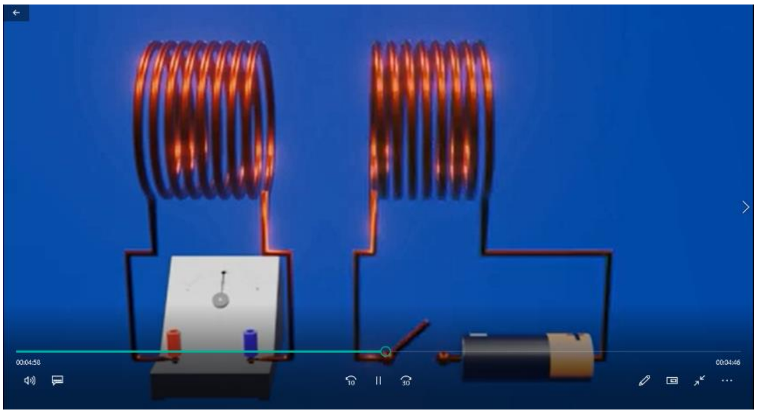


Figure 4.3.29 Screenshot showing induced current due to change in magnetic flux. Source: Researcher's own.

The teacher opened and closed the switch in the second coil to produce a change in magnetic flux. He indicated that:

> *Therefore, the reason that Induced current is mainly due to change in magnetic flux and not due to motion of magnet.*

He went further to explain the direction of the induced current in figure 4.3.30 in terms of Lenz's law and direction of the induced magnetic field in terms of the RHR.

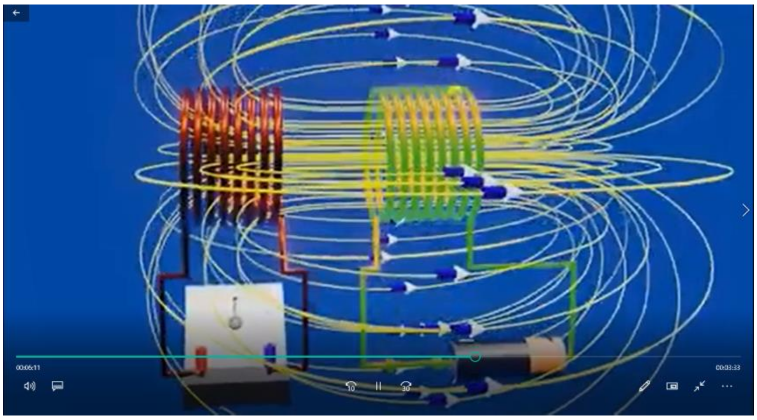


Figure 4.3.30: Screenshot showing simulation diagram used to explain RHR and Lenz's law. Source: Researcher's own

The teacher touched on Lenz's law to explain the direction of the induced current and the significance of the negative sign in Faraday's formula. In his explanation, he mentioned that:

> *…….a closer look at the video simulation also tells us that the induced magnetic field opposes that of the approaching magnet and change in flux*

This was further demonstrated using a video of simulation, as shown in figure 4.3.31, in which he made his learners observe that the direction of the induced current always opposes motion producing it.

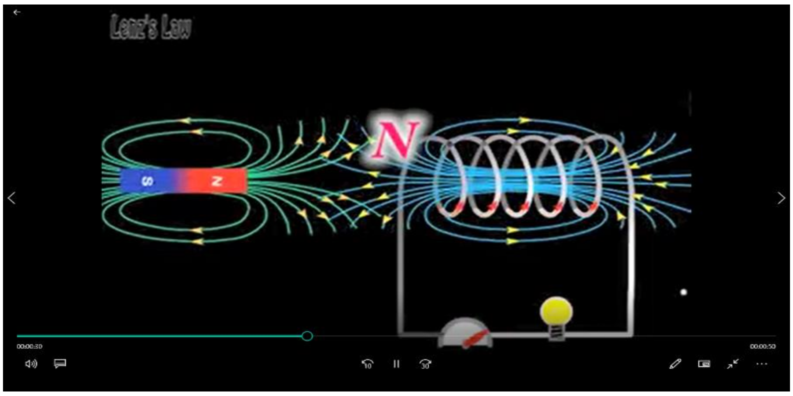


Figure 4.3.31: Screenshot showing simulation diagram used to explain Lenz’s law. Source: Researcher’s own.

The teacher said:

> *To predict the direction of the induced current we apply the right-hand rule.*

The teacher placed some emphasis on how to apply the RHR to the induced current:

> *Please note when current is induced in the coil, it creates its own magnetic field around the coil. Therefore, we apply the right-hand rule to the magnetic field of the induced current and not magnetic field of the bar magnet.*

Furthermore, he gave learners two worked examples based on numerical calculations before giving them some questions to attempt as individuals in their classwork books.

Section 4 Conclusion [3min 29sec]:

TE3 then concluded the lesson by providing a brief summary of the entire lesson. He made mention of the application of the EMI in electric generators. Homework was given based on both magnetic flux and Faraday’s law.

4.4.5 TEACHER TE3’S VSRI RESPONSES.

The transcript of TE3’s VSRI session is available in Appendix E3. The VSRI session was held at TE3’s school three days after conducting video-recorded lesson observations. The responses given by the teacher gave the researcher an idea about the intrinsic nature and level of development of his personal PCK and, how the teacher justified his approach to the enactment of his PCK based on available video-recorded evidence. In this section the researcher presents some of the responses to specific questions posed to him during the VSRI session.

The teacher demonstrated some confidence while responding to a question based on his general impression of the entire video clip of him teaching the big ideas of MF and FL to his learners.

During the VSRI session the teacher justified his introductory approach saying that:

> *The short video was just a brief summary of the two big ideas, and it was meant to give my learners the overall impression of what to expect in the lesson. It is important for me to try and make my learners to stay alert and motivated from the beginning till the end. From my few experiences in teaching, I have noted that most learners love lessons blended with videos.*

During the VSRI session the teacher justified his introductory approach saying that:

> *It is important for me to try and make my learners to stay alert and motivated from the beginning till the end. From my few experiences in teaching, I have noted that most learners love lessons blended with videos.*

During the VSRI session while responding to a question based on why he opted to introduce the big idea of FL with a video, he indicated that:

> *I wanted my learners to have a complete picture of electromagnetic induction as well as an overall impression about Faraday's law. I also used the video as a motivational tool to capture their attention.*

During the VSRI session while responding to a question about why he used equipment that was not working to demonstrate induction, the teacher indicated that:

> *I wanted to expose my learners to the laboratory apparatus used in real experiment of electromagnetic induction, and also enable them to have the correct mental of how induction is practically conducted. It's also a working strategy I used to capture their attention.*

While teaching the first big idea of MF, the teacher made use of chalkboard diagrams supported with some explanatory notes. However, no experiments, or video simulations were used to further emphasise on the big idea of MF and the significance of the angle. During the VSRI session the teacher indicated that:

> *I have personally never been able to witness an experiment based on magnetic flux. Therefore, I thought there was no need to even to think about video simulations based on magnetic flux only. However, the video simulations based on Faraday's law could also be used to emphasise on magnetic flux like I did at last.*

When asked to comment on his areas of strength regarding teaching Faraday’s law, he expressed some confidence saying:

> *In as far as my understanding of Faraday’s law is concerned, i don’t have a section where I can doubt myself. I may not be sure of whether my learners understood my explanations ……….*

Responding to a question based on why he opted to introduce the big idea of FL with a video, he indicated that:

> *I wanted my learners to have a complete picture of electromagnetic induction as well as an overall impression about Faraday’s law. I also used the video as a motivational tool to capture their attention. It’s just unfortunate that these were the only apparatus that I had.*

During a video playback, while teaching Faraday’s law, he showed learners some of the apparatus used to verify the law. He went further to show learners how the apparatus was to be practically connected. However, no deflection on the meter was noted by learners. During the VSRI session while responding to a question pertaining to his use of dysfunctional equipment for demonstration as to whether he did some pre-trial experiment before the lesson, he indicated that:

> *I wanted to expose my learners to the laboratory apparatus used in real experiment of electromagnetic induction, and also enable them to have the correct mental of how induction is practically conducted. It’s also a working strategy I used to capture their attention.*

While responding to a question based on the areas that needed his serious attention if accorded the chance to teach EMI in future TE3 responded saying

> *…………I don’t feel like I have done adequately without conducting some experiments. I think next time, I really need to give maximum attention to my representation methods that I use when treating especially the second big idea of Faraday’s law. I shall also try to make some prior arrangements to borrow equipment from schools within our cluster or neighbourhood. If that doesn’t materialise, then I shall have to explore the use of virtual labs.*

When asked to comment about his views pertaining to the idea of teachers having to video-record their lessons, the teacher mentioned that:

> *I have fallen in love with video recorded lesson. It’s an evidence-based lesson. The easiest way I can be able to reflect on my lesson without being biased is only if I can*

> *video record it and then do the playback. I will also be quickly able to observe my areas of strength and weaknesses.*

4.4.6 SEMI-STRUCTURED INTERVIEW RESPONSES

The transcript of the semi-structured interview (SSI) session is available in Appendix F3. An SSI session was conveniently carried out at TE3's school and in his office, after school hours to avoid disrupting his school-based programmes. The SSI session was carried out two days after the video-recorded EMI lesson observation. The entire SSI session lasted for thirty-one minutes.

During the SSI session, the teacher was asked whether he managed to achieve the intended goals and objectives as suggested in his post intervention CoRe. In his response he mentioned that he managed to address all the bullets about magnetic flux and Faraday's law as specified in the CAPS document. He mentioned that:

> *I can also attribute this to my ability to follow what I had outlined in my post intervention CoRe. This made it possible for me to teach both magnetic flux and Faraday's law in just one lesson.*

When asked to comment on his teaching strategies prior to intervention compared to his post-intervention strategies TE3 acknowledged that there was a noticeable difference.

> *Many of us teachers have fair amount of subject content knowledge, but the teaching methodology is a cause for concern. Hence, there is need for continued professional development. But once your methods of teaching are upgraded, the level of learner understanding of concepts will increase. I considered my methods of teaching to have been upgraded especially through the use of CoRes and also video stimulated recall.*

While responding to a question based on whether the training, he received during the period of intervention had any positive impact on him as a teacher, TE3 responded saying that he acknowledged the whole idea behind the use of the content representation tool prior to lesson execution.

> *The CoRe actually allows you to be able to address all facets of an abstract concept such as EMI. Even the use of video recording your lesson and playing it back after will aid you in discovering your pedagogical shortfalls and strength. This will assist you in re-strategizing. Yeah, the impact was huge and positive.*

While addressing a question based on what he thought made the teaching and learning of EMI difficult for learners, he cited the lack of enough laboratory resources as a main cause as he would end up relying on textbooks for explanations. Furthermore, he mentioned that the EMI section just like any other section in Physics required a lot of imagination.

The attribute of imagination is what tends to be lacking amongst most of our learners.

When asked about what he liked and did not like about the intervention, TE3 mentioned the completion of the CoRe tool followed by the video-recorded lesson observation as plausible approaches to teaching sections like EMI. However, TE3 disliked the high amount of writing involved in completing the content representation instrument as well as the normal planning. He went on to say:

> *I wish if it can just replace what we call our daily lesson preparation. Because if you complete the CoRe tool and then go on to do lesson preparation, it becomes hectic.*

4.4.7 SCORING ENACTED PCK for TE3

In this section, the researcher links what transpired during the lesson observation with the teacher's VSRI and SSI aftermath responses to evaluate his enacted PCK. The scores were assigned to each of the specific PCK components based on the video recordings of the lesson observations and after the VSRI and SSI sessions with the teacher. Table 4.3.5 presents these scores. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

This discussion focuses on interesting aspects of TE3's PCK enactment in view of the selected key ideas in his CoRes.

Table 4.3.5: Scores of TE3 based on enacted PCK

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency					x	o		
2	Learner understanding					x	o		
3	Conceptual teaching strategies					x	o		
4	Representations					x	o		

4.4.7.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea based on MF, he wrote the definition of magnetic flux and verbally explained by paraphrasing it. In his explanation he indicated that:

……In other words, magnetic flux ∅ is a measure of the total magnetic field lines passing a loop of predictable cross-sectional area. The stronger the magnetic field B passing through an area of loop A, the higher the magnitude of the magnetic flux.

He went on to present the flux formula and interpreted the physical meaning of each symbol in the formula. He mentioned the SI unit of magnetic flux as weber (Wb) and magnetic field strength as tesla (T).

Consequently, his ePCK for this component based on MF was awarded a score of '*developing*'. This score is justified by the fact that 'subordinate ideas that account for the application of equations and definitions are identified' as stated in the rubric. Furthermore, the 'subordinate ideas that account for the application of equations and definitions are identified', as stated in the rubric.

For the second big idea based on FL, the teacher covered the sections relating to stating Faraday's law, he presented the mathematical formula of Faraday and explained the physical significance of the negative sign in the formula. The direction of the induced current was explained in terms of Lenz's law. Furthermore, the teacher used video simulations to explain the application of the RHR in predicting the direction of the induced current. However, the teacher's attempt to demonstrate Faraday' law experimentally failed (see section 4.4.7.3 for the teacher's remarks about the failed experiment).

The teacher's ePCK for this component based on FL was scored as '*developing*'. This is because the teacher's 'Content knowledge is evident and there is evidence of knowledge about sequencing and scaffolding of concepts', as stated by the rubric. However, 'knowledge about logical scaffolding and sequencing of ideas' was not observed, therefore the score is not exemplary.

4.4.7.2 KNOWLEDGE OF LEARNER UNDERSTANDING

Before introducing magnetic flux, the teacher started off by briefly recapping the ideas centred around the magnetic effect of current carrying coil. The teacher went on to introduce the concept of MF.

While teaching the concept of magnetic flux, the teacher placed more emphasis on the difference between magnetic flux and magnetic field strength:

> *Magnetic field strength refers to a measure of the strength and direction of the magnetic field while magnetic flux refers to the product of component of magnetic field perpendicular to a surface and cross-sectional area of the loop in which the field passes through.*

The teacher placed some emphasis on the significance of the angle between an imaginary line drawn normal to the loop and the magnetic field. He cautioned his learners not to use any angle that will be provided for them during numerical calculations. When asked during the VSRI session about why learners should not use any angle provided to them the teacher said:

> *Some learners tend to develop some misconception related to the angle. Sometimes questions are presented in such a way that learners must figure out or even calculate the angle between normal line and the field. So, if learners just use any angle given to them, they will end up being trapped by some questions.*

When asked during the VSRI session, the teacher indicated that:

> *The calculations become difficult especially if the angle is mis-interpreted or incorrectly determined.*

The teacher's ePCK for this component based on MF was scored as '*developing*'. This is because 'appropriate difficulties for two of the main ideas were identified and clearly formulated', as stated by the rubric.

Before introducing Faraday's law, the teacher had taught his learners about magnetic flux and change in magnetic flux. However, the rate of change in magnetic flux and relative motion between coil and magnet were only mentioned during and after introducing Faraday's law. In his submission during the VSRI session, the teacher pointed out that:

> *While it's a noble idea to expose learners to the physics of relative motion and rate of change in magnetic flux, but the explanation is more vivid when contextually dealing with Faraday's law.*

The teacher introduced the second big idea of FL using a video based on electromagnetic induction (see Figure 4.3.24). He then went on to verbally explain Faraday's law with the aid of chalkboard notes. While explaining Faraday's formula, he placed emphasis on the significance of the negative sign in the formula.

> *This means that the negative sign in Faraday's formula has to do with the direction of induced current which is predicted using Lenz's law…………*

The teacher went on to explain the RHR in conjunction with Lenz's law as explained in section 4.4.7.3. Many learners were able to individually attempt the questions based on numerical calculations using Faraday's law. Furthermore, most learners could easily recall the factors necessary to increase the EMF output. However, no examples of questions based on Lenz's law were given to the learners.

Consequently, the teacher's ePCK for this component based on FL was scored as '*developing*'. This is because 'appropriate difficulties for two of the main ideas are identified and clearly formulated', as stated by the rubric.

4.4.7.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea based on MF, some chalkboard explanatory notes based on the definition of magnetic flux were given. The teacher made use of chalkboard diagrams aided by some verbal explanations as a CTS while treating the significance of angle θ. A class activity based on numerical calculations using flux formula was used during the lesson. However, no video or video simulation was used as a CTS to aid in explaining the flux concept to the learners. During the SSI session while responding to a question based on the kind of support, he might need to improve his teaching of electromagnetic induction he said:

> *I wish if I could get someone to assist me with videos or simulation videos based specifically on magnetic flux. Or if there is someone out there who might assist me with a practical way of demonstrating the existence of to the learners.*

The teacher's ePCK for this component based on MF was scored as '*developing*'. This is because the overall strategy is workable and there is evidence of encouragement of learner involvement ' as stated by the rubric.

For the second big idea based on FL, the teacher introduced FL using a video shown in figure 4.3.24. He then attempted to practically demonstrate Faraday's law to his learners using a bar magnet and coil connected to the ammeter as shown in figure 4.3.25. However, the demonstration was unsuccessful since no deflection could be observed on the voltmeter. He held the magnet too far from the coil, and the typical laboratory voltmeter shown on the picture was too insensitive to show induction in this setup. He needed a galvanometer and was supposed to push the magnet into the coil. So, he demonstrated lack of knowledge of laboratory equipment. During the VSRI session the teacher responded to a question based on why there was no deflection on his voltmeter and said:

> *It might be that the magnet was too weak to cause any deflection or the ammeter itself was having a problem. I suppose, I should have started by testing the equipment before bringing them to class. But anyway, at least I exposed the learners to the actual apparatus and also showed them how to connect them.*

The teacher presented Faraday's law statement and formula on the chalkboard and went on to verbally explain the law and physical meaning of the symbols used in the formula as shown in figure 4.3.26. He explained further the RHR and the direction of induced current using the chalkboard as shown in figure 4.3.27. However, he did not clarify that the polarity is first determined by Lenz's law, and then the direction of the induced current is found by the RHR.

> *This means that the negative sign in Faraday's formula has to do with the direction of induced current which is predicted using Lenz's law. The induced current also creates a magnetic field around the coil whose polarity can be predicted by applying the right-hand rule.*

The use of video simulation motivated the learners and incited higher levels of participation. During the video simulation presentation, learners were able to correctly respond to some of the guiding questions posed to them. However, learners were not asked to apply Lenz's law themselves.

The teacher's ePCK for this component based on FL was scored as '*developing*'. This is because 'at least two different levels of representation to enforce an aspect or concept', but 'attention being paid to sequencing for conceptual development is not evident', as stated in the rubric.

4.4.7.4 REPRESENTATIONS

For the first big idea of MF, the teacher used symbols on the chalkboard to represent magnetic flux. The teacher drew chalkboard diagrams to represent the angle between the line normal to the loop and magnetic field as shown in figure 4.3.22. However, lack of three-dimensional representation may lead to learners' misunderstanding.

The teacher used mathematical symbols and explanatory notes as a way of representation while explaining the flux formula as shown in figure 4.3.21. However, the teacher was unable to represent the concept of flux using the video simulations. During the VSRI session, the teacher indicated:

> *There is no way I could have independently represented a video simulation based only on the flux concept without involving Faraday's law of electromagnetic induction. That is why I had to also reiterate the flux concept during my video simulation presentation to the class.*

The teacher's ePCK for this component based on MF was scored as '*developing*'. This is because 'some evidence is given of the use of representations to support conceptual development', as stated by the rubric.

For the second big idea of FL, the teacher used videos and video simulations in addition to chalkboard explanatory notes to represent Faraday's law. The symbols used in Faraday's formula were represented on the chalkboard. However, the teacher's attempt to represent Faraday's law through a practical demonstration was not successful as no deflection was observed on the ammeter. Furthermore, the teacher made no attempt to draw diagrams on the chalkboard to represent induction in accordance with Faraday's law.

The teacher's ePCK for this component based on FL was scored as '*developing*'. This is because 'some evidence is given of the use of representations to support conceptual development', as stated by the rubric.

4.4.8 COMPARISON OF TE3's ENACTED PCK with his POST-INTERVENTION CoRes

Table 4.3.6 shows a summary comparing the post-intervention and enacted PCK scores per big idea.

Table 4.3.6: Comparison of TE3's post intervention and enacted PCK scores

PCK Component	**PCK SCORING LEVEL SUMMARY**															
	POST								**ENACTED**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency							x	o					x	o		
Learner understanding					x	o							x	o		
Conceptual teaching strategies						o	x						x	o		
Representations							x	o					x	o		

From table 4.3.6, the following observations were made regarding post-CoRe scores compared to enacted PCK scores:

The immediate observations which one would make is that the PCK scores shifted from predominantly developing (D) and exemplary (E) in post-intervention CoRe to predominantly developing (D) during the enactment of PCK.

The scores not highlighted at all is an indication that there was no noticeable change in enacted PCK scores compared to post-intervention scores. The scores highlighted in green show a noticeable decrease in enacted scores compared to post-CoRe scores. The green highlighted scores provide evidence that the teacher's personal PCK was not fully enacted during teaching. For example, the teacher mentioned in his post-CoRe that he would make use of video simulations to represent the big idea of MF. However, there is no evidence from his video-recorded lesson of him showing learners a video simulation based on magnetic flux. Instead, he mentioned it verbally while presenting the video simulation related to the second big idea of the flux.

In his post-CoRes, the teacher mentioned that he would use practical demonstration as part of his CTS to represent Faraday's law of electromagnetic induction. However, the practical demonstration was not successful as the magnet used could not cause any noticeable deflection on his ammeter.

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in table 4.1.7. Table 4.3.7 shows the comparative PCK scores on a numerical scale.

Table 4.3.7: Summary of TE3's comparative PCK scores on a scale ranging from 1 to 4.

PCK Components	**Scores**					
	Post-CoRe			**Enacted PCK**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular Saliency	4	4	4.0	3	3	3.0
Learner understanding	3	3	3.0	3	3	3.0
Conceptual teaching strategies	4	3	3.5	3	3	3.0
Representations	4	4	4.0	3	3	3.0
Total (16)	15	14	14.5	12	13	12.0
Average (4)	3.8	3.5	3.6	3.0	3.0	3.0

From the numerical scores in Table 4.3.7, there was a noticeable difference between post-CoRe scores and ePCK scores based on the big idea of MF, decreasing by an average of 0.8 points (from a score of 3.8 to 3.0). Furthermore, there was an even larger difference between post-CoRe scores and ePCK scores that was observed based on the second big idea of FL. The enacted PCK scores based on the big idea of FL decreased by an average of 0.5 points (from a score of 3.5 to 3.0) for PCK enactment. Combining the two big ideas, the overall average score also decreased by an average of 0.6 points (from 3.6 for post-CoRe to 3.0) for ePCK, indicating that the teacher's personal PCK was ineffectively enacted during teaching.

4.5 THE CASE OF TEACHER TE4

Teacher TE4 is a young female in-service teacher in her mid-20s. She is in her second year of teaching after graduating from one of SA's state-owned universities with a B Ed degree majoring in Physical Sciences and Mathematics. In 2021, the time when this study was conducted, it was her first year of teaching Physical Sciences to the Grade 11 learners.

Teacher TE4's is permanently attached to a combined school located in Mpumalanga province. The school offers Grades R to 12 and had an overall enrolment of 910 learners at the time of conducting the study. The school follows the curriculum prescribed in the CAPs document. At the time of this study, there were 45 Physical Sciences learners in Grade 11. The school was one of those conveniently sampled for this study due to its easy accessibility to the researcher.

During my first visit to her school, the teacher mentioned that she would need at least four periods to complete the Grade 11 topic of electromagnetism. For her recorded lesson, she combined magnetic flux and Faraday's law. The findings based on how she constructed her pre-CoRes, post-CoRes and, later enacted her PCK based on MF and FL are detailed in the following sub-sections from 4.5.1 to 4.5.8.

4.5.1 PRE-INTERVENTION CoRes

TE4 responded to all sections of the pre-intervention CoRe, shown in Appendix **A4**. Table 4.4.1 shows the result of the scores obtained after a thorough assessment of responses, separately for each of the big ideas of MF and FL. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components

Table 4.4.1: Scores of TE4 based on pre-intervention CoRes in the big ideas of magnetic flux (MF) and Faraday's law (FL)

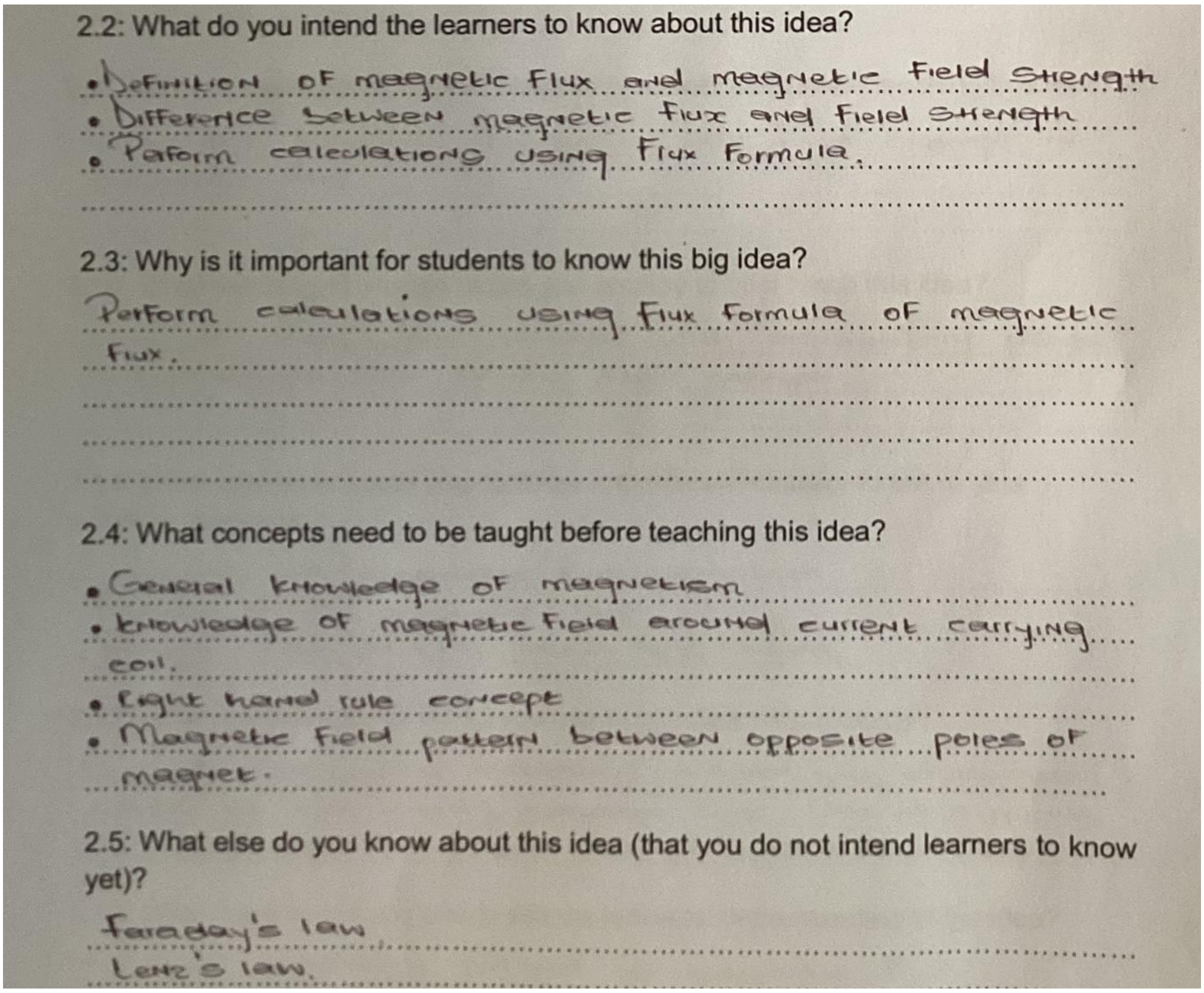
PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency			x	o				
2	Learner understanding			x	o				
3	Conceptual teaching strategies			x	o				
4	Representations		o	x					

4.5.1.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, shown in figure 4.4.1, her response to question 2.2 indicated that she wants her learners to know the definition of magnetic flux and magnetic field strength and able to perform calculations related to the magnetic flux. However, she did not mention anything about understanding the meaning of the angle in the flux formula.

Furthermore, she did not mention in her response to question 2.3 that students should know flux in order to understand FL. In her response to question 2.4 the teacher indicated general knowledge of magnetism, the existence of the magnetic field around a current-carrying coil and the RHR as concepts that needed to be taught before teaching magnetic flux. Furthermore, she indicated that the learners ought to know about magnetic field patterns between opposite poles of magnets before being taught about MF. While responding to question 2.5, Faraday's law and Lenz's law were mentioned as things which she knows and are not yet known by her learners.

However, there was no need for the teacher to mention RHR while responding to question 2.4 since the concept is not linked to MF.



2.2: What do you intend the learners to know about this idea?

- Definition of magnetic flux and magnetic field strength
- Difference between magnetic flux and field strength
- Perform calculations using flux formula.

2.3: Why is it important for students to know this big idea?

Perform calculations using flux formula of magnetic flux.

2.4: What concepts need to be taught before teaching this idea?

- General knowledge of magnetism
- knowledge of magnetic field around current carrying coil.
- Right hand rule concept
- Magnetic field pattern between opposite poles of magnet.

2.5: What else do you know about this idea (that you do not intend learners to know yet)?

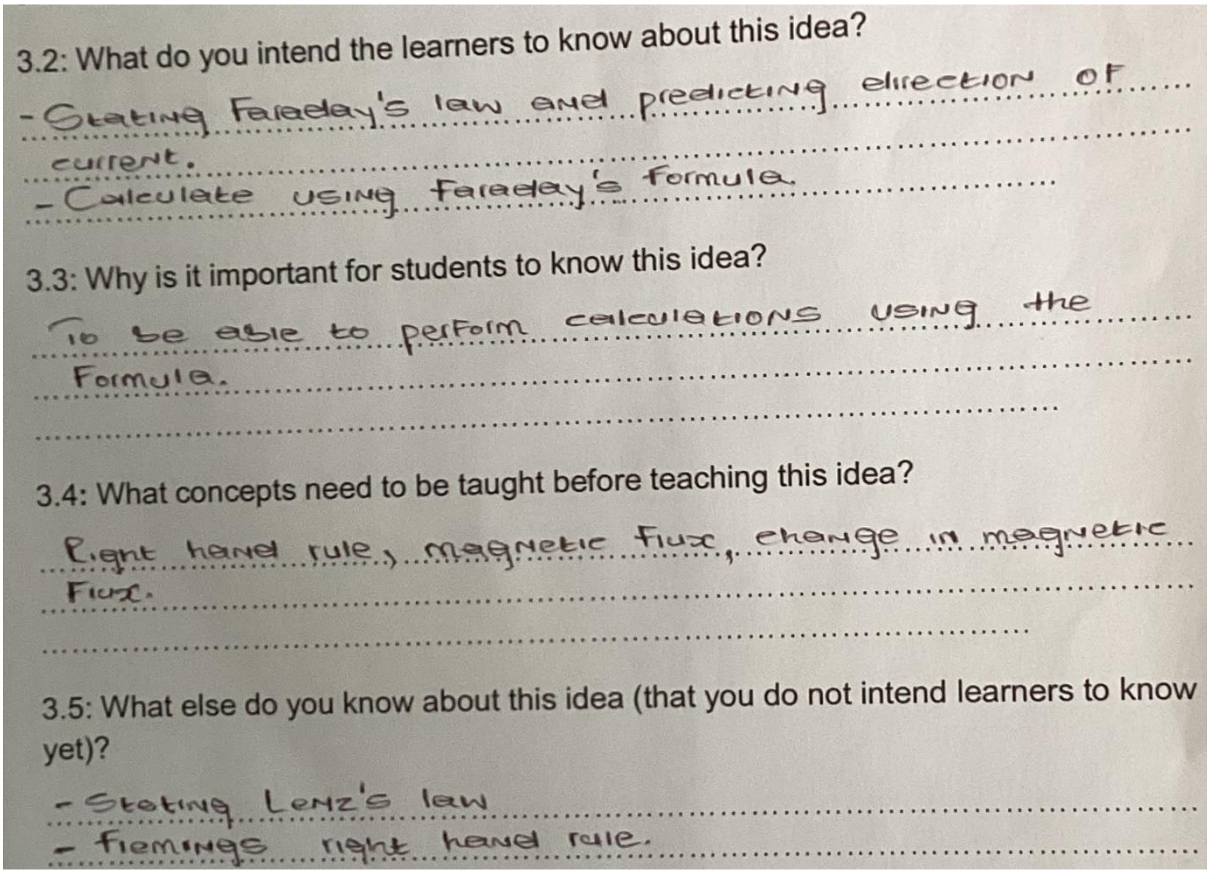
Faraday's law

Lenz's law.

Figure 4.4.1 Snapshot of TE4's pre-CoRe responses regarding her knowledge of curricular saliency for MF. Source: Researcher's own.

The teacher's pPCK for this component prior to intervention based on the big idea MF was therefore scored as '*adequate*'. This is because 'important sub-ordinate ideas are omitted' as stated by the rubric.

For the second big idea of FL, shown in figure 4.4.2, stating Faraday's law and prediction of direction of induced current were mentioned as responses to question 3.2. The teacher indicated in her response to question 3.3 that it was imperative for learners to be taught Faraday's law so that they will be able to perform calculations based on Faraday's formula. However, she does not mention that the generating of electricity relies on induction, so FL is very important in everyday life. In her response to question 3.4, she mentioned that it was imperative for the learners to be exposed to RHR, flux and change in flux as pre-concepts before teaching them Faraday's law.



3.2: What do you intend the learners to know about this idea?

- Stating Faraday's law and predicting direction of current.
- Calculate using Faraday's formula.

3.3: Why is it important for students to know this idea?

To be able to perform calculations using the formula.

3.4: What concepts need to be taught before teaching this idea?

Right hand rule, magnetic flux, change in magnetic flux.

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

- Stating Lenz's law
- Flemings right hand rule.

Figure 4.4.2 Snapshot of TE4's pre-CoRe responses regarding her knowledge of curricular saliency for FL. Source: Researcher's own.

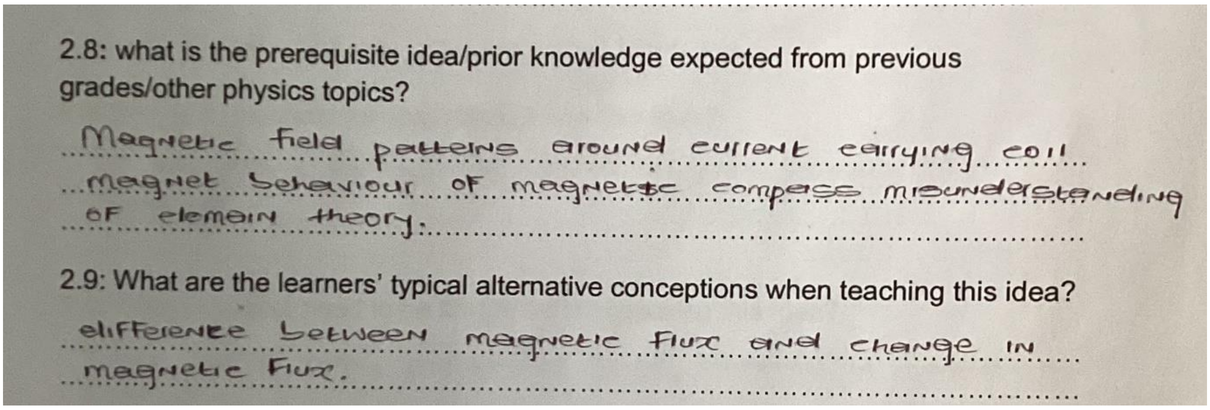
The teacher mentioned in her response to question 3.5, stating Lenz's law as something which she knows but does not want her learners to know yet. Furthermore, mentioning Fleming's RHR was not necessary as it is only be treated in the Grade 12 CAPS section of generators.

Her response to question 3.5 was in agreement with the CAPS syllabus which demands that the learners be taught the direction of induced current and not explicitly Lenz's law. The CAPS document indeed, does not explicitly mention Lenz's law.

The teacher’s pPCK for this component prior to the intervention based on the big idea FL was therefore scored as ‘*adequate*’. This is because ‘there is some evidence of knowledge about sequencing or scaffolding’ as stated by the rubric. Furthermore, the ‘identified concepts refer to elementary concepts generally regarded as basic to the subject or topic’, as stated by the rubric.

4.5.1.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, shown in figure 4.4.3, the existence of magnetic field patterns due to field lines around a current carrying coil was cited as learners’ prior knowledge before the treatment of magnetic flux. The teacher cited the behaviour of a magnetic compass placed closer to a magnetic pole perhaps to predetermine whether a given pole is north or south pole. Misunderstanding of the domain theory was quoted as prior knowledge. It is difficult to understand what she meant because the points she mentioned in response to question 2.8 were not separated with commas or linked in any way.



2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic field patterns around current carrying coil
magnet behaviour of magnetic compass misunderstanding
of elemain theory.

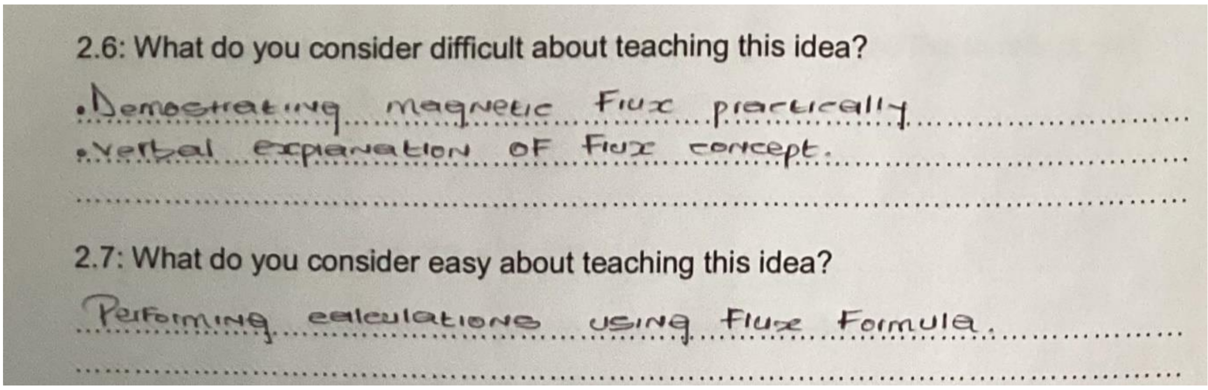
2.9: What are the learners’ typical alternative conceptions when teaching this idea?

difference between magnetic flux and change in
magnetic flux.

Figure 4.4.3 Snapshot of TE4’s pre-CoRe responses regarding learner’s prior knowledge for MF. Source: Researcher’s own.

In her response to question 2.9, shown in figure 4.4.3, the teacher mentioned the difference between magnetic flux and flux change as a learner misconception.

Experimentally demonstrating magnetic flux was mentioned in figure 4.4.4 as something difficult while teaching. Furthermore, explaining the concept of flux to learners was mentioned to be difficult.



2.6: What do you consider difficult about teaching this idea?

- Demostrating magnetic flux practically
- verbal explanation of flux concept.

2.7: What do you consider easy about teaching this idea?

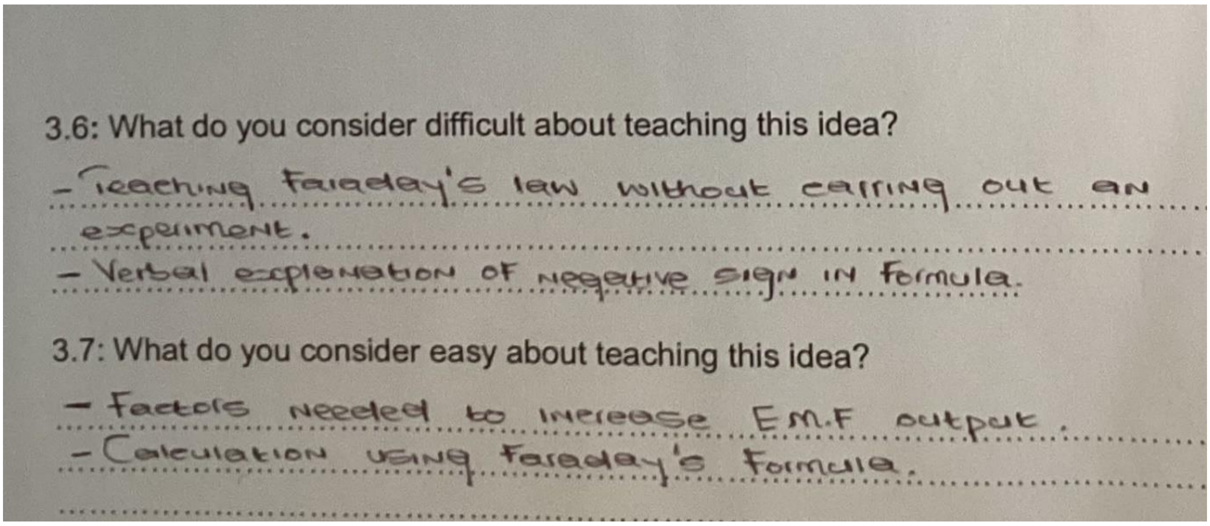
Performing calculations using flux formula.

Figure 4.4.4 Snapshot of TE4’s pre-CoRe responses regarding learner understanding for MF. Source: Researcher’s own.

However, she made no mention of whether the significance of the angle between the magnetic field and the imaginary line drawn normal to the coil in flux formula or calculation of the angle was easy or difficult to teach. The difference between flux and flux change was not mentioned as to whether it was difficult or easy to teach, though she indicated it as a misconception in her response to question 2.9.

The teacher’s pPCK for this component prior to intervention based on the big idea MF was therefore scored as ‘*adequate*’. This is because ‘an appropriate difficulty related to only one of the main ideas is identified and clearly formulated’ as stated by the rubric.

For the second big idea of FL, shown in figure 4.4.5, explaining Faraday’s law with no exposure to real experiments or the use of computer simulations was considered as difficult to teach. Furthermore, an explanation that accounts for the existence of the negative sign in Faraday’s formula was mentioned as a difficult part to teach. Teaching factors governing EMF output and performing calculations using Faraday’s formula were mentioned as something which makes it easier to teach FL.


3.6: What do you consider difficult about teaching this idea?

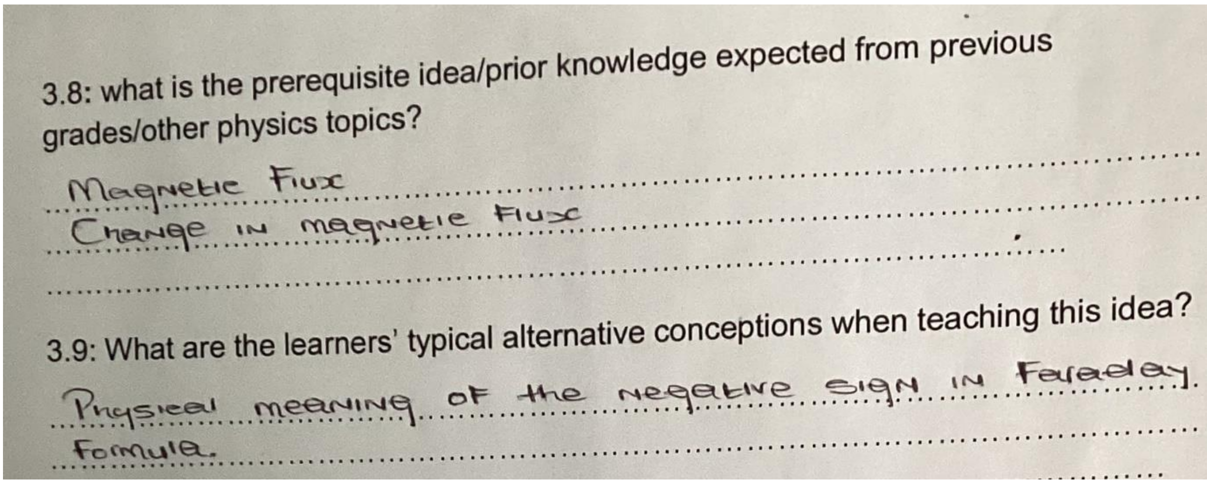
- Teaching Faraday's law without carring out an experiment.
- Verbal explanation of negative sign in formula.

3.7: What do you consider easy about teaching this idea?

- Factors needed to increase E.M.F output.
- Calculation using Faraday's formula.

Figure 4.4.5 Snapshot of TE4's pre-CoRe responses regarding learner understanding for FL. Source: Researcher's own.

Shown in figure 4.4.6, magnetic flux, change in flux, and EMF were cited as prerequisites for learners to conceptualise Faraday's law. On the other hand, the physical significance of the negative sign in Faraday's formula was considered a likely source of misconception, even though she did not explain how learners misunderstand the minus.


3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic Flux
Change in magnetic Flux

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Physical meaning of the negative sign in Faraday Formula.

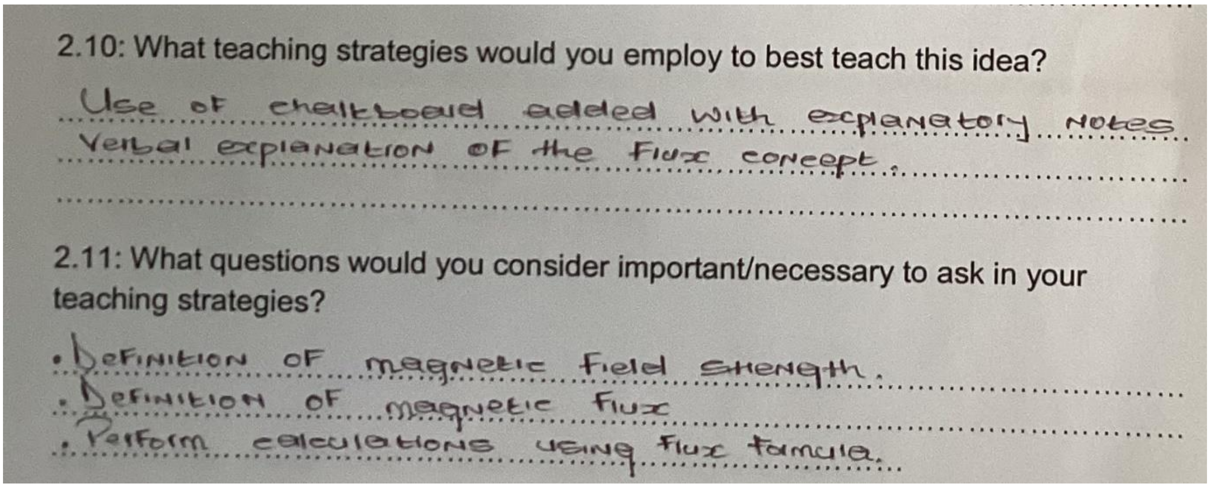
Figure 4.4.6 Snapshot of TE4's pre-CoRe responses regarding *learner understanding* for FL. Source: Researcher's own.

However, the teacher did not mention whether the RHR's application to predict direction of induced current was easy or difficult during actual teaching. Furthermore, the teacher did not mention the difference between flux change and rate of flux change as a potential source of alternative conceptions amongst the learners.

Consequently, the teacher's PCK in this component prior to intervention based on the second big idea FL was scored as '*adequate*'. This is because 'an appropriate difficulty related to only one of the main ideas is identified and clearly formulated' as stated by the rubric. The teacher did not cite the RHR as a prerequisite needed in predicting the direction of induced current.

4.5.1.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, shown in figure 4.4.7, the teacher indicated the use of chalkboard diagrams aided by explanatory notes and verbal explanation as CTS to illustrate magnetic flux and calculations using the flux formula. As part of her CTS, she proposed to ask her learners some questions based on their recall of definitions and performing calculations, but did not refer to the angle at all.



2.10: What teaching strategies would you employ to best teach this idea?

Use of chalkboard added with explanatory Notes

Verbal explanation of the Flux concept.

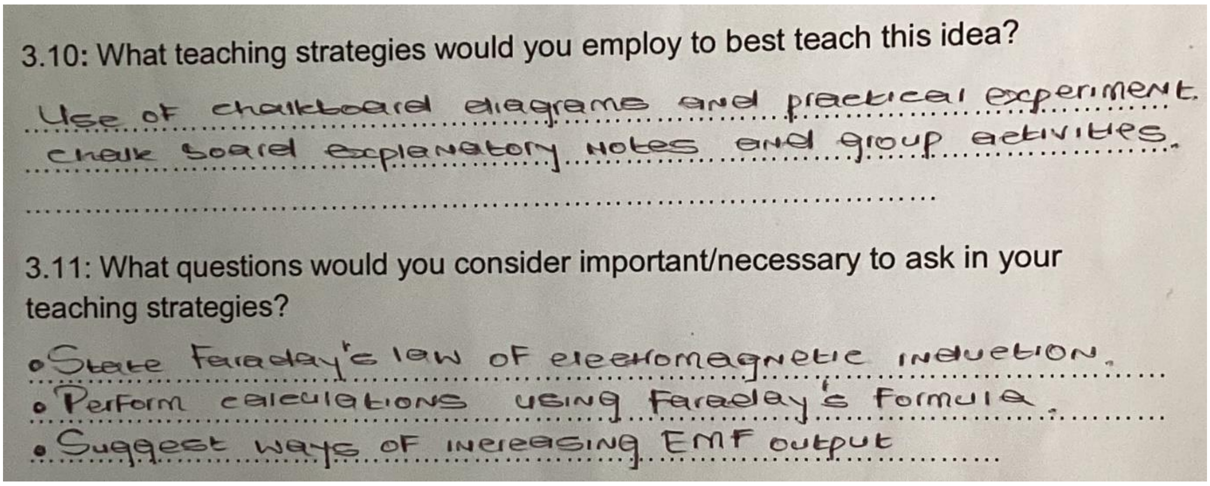
2.11: What questions would you consider important/necessary to ask in your teaching strategies?

- Definition of magnetic field strength.
- Definition of magnetic flux
- Perform calculations using flux formula.

Figure 4.4.7: Snapshot of TE4's pre-CoRe responses regarding her CTS for MF. Source: Researcher's own.

The teacher's pPCK for this component based on the first big idea of MF prior to intervention was therefore scored as '*adequate*'. This score is justified by the fact that 'the response indicates general teaching strategies with limited explanation of application and questions do not require higher order thinking skills' as stated by the rubric.

For the second big idea of FL, shown in figure 4.4.8, the teacher suggested the use of chalkboard diagrams and practical experiments as part of her CTS. Furthermore, chalkboard explanatory notes and, group activities were proposed as part of her CTS. In her response to question 3.11, the teacher proposed to ask some questions which include stating Faraday's law of electromagnetic induction, using Faraday's formula to perform some calculations and suggesting means or ways of increasing the output of EMF signal.


3.10: What teaching strategies would you employ to best teach this idea?

Use of chalkboard diagrams and practical experiment.
chalk board explanatory notes and group activities.

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

- State Faraday's law of electromagnetic induction.
- Perform calculations using Faraday's formula.
- Suggest ways of increasing EMF output

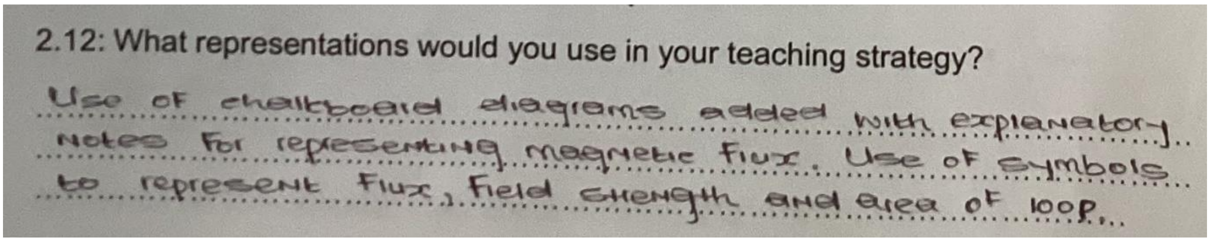
Figure 4.4.8: Snapshot of TE4’s pre-CoRe responses regarding her CTS for FL. Source: Researcher’s own.

However, the teacher made no mention of how she was going to address the issue of the direction of the induced current as part of her CTS.

The teacher’s pPCK for this component prior to intervention based on the big idea FL was therefore scored as ‘*adequate*’. This is because ‘the response lacks aspects of curriculum saliency and indicates general teaching strategies with limited explanation of application’, as stated by the rubric. Furthermore, ‘there is no evidence of acknowledgement of student prior knowledge and misconceptions’, as stated in the rubric. The teacher did not mention the RHR and how it can be addressed as part of her CTS based on FL

4.5.1.4 REPRESENTATIONS

For the first big idea of MF, shown in figure 4.4.9, the teacher proposes to use chalkboard diagrams aided by explanatory notes for representing magnetic flux. The teacher suggested to use mathematical formulae as a representation of symbols used in flux formula. Furthermore, the teacher suggested to do a practical to teach the concept of magnetic flux.

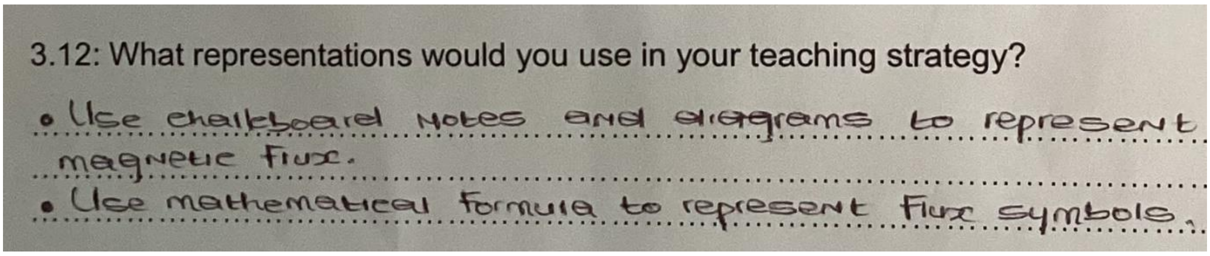

2.12: What representations would you use in your teaching strategy?

Use of chalkboard diagrams added with explanatory notes for representing magnetic flux. Use of symbols to represent flux, field strength and area of loop.

Figure 4.4.9: Snapshot of TE4’s pre-CoRe responses regarding her representations for MF. Source: Researcher’s own.

The teacher’s pPCK for this component based on the first big idea of MF prior to intervention was scored as ‘*adequate*’. This score is justified by the fact that ‘the selection of representations (visual or symbolic) is insufficient', as stated by the rubric. Furthermore, 'there is no evidence how the use of the representation will lead to increased understanding of concepts', as stated by the rubric.

For the second big idea of FL, shown in figure 4.4.10, the teacher's suggested representations were for the big idea of MF. Nothing involving the second big idea of FL was mentioned in response to question 3.12.



3.12: What representations would you use in your teaching strategy?

- Use chalkboard notes and diagrams to represent magnetic flux.
- Use mathematical formula to represent flux symbols.

Figure 4.4.10: Snapshot of TE4's pre-CoRe responses regarding her representations for FL. Source: Researcher's own.

The teacher's pPCK for this component prior to intervention based on the big idea FL was therefore scored as '*limited*'. This is because 'representations are mentioned with no explanation of specific links to the concepts considered' as stated in the rubric. The teacher mentioned nothing involving the second big idea of FL while responding to question 3.12.

4.5.2 DISCUSSION OF POST-INTERVENTION CoRes

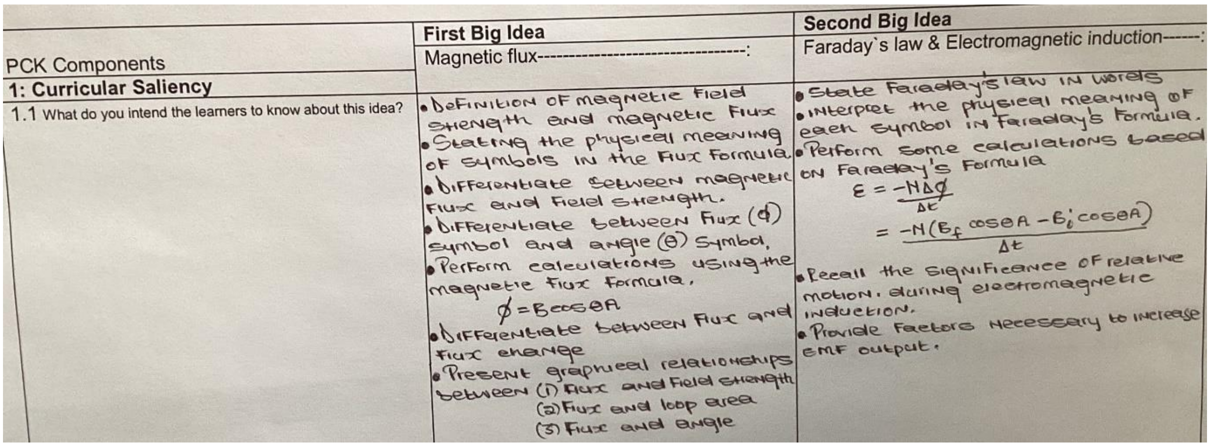
Table 4.4.2 shows the score results obtained after a thorough scrutiny of responses given in TE4's completed post-intervention CoRe based on Grade 11's EMI section of electromagnetism (see Appendix C4). Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

Table 4.4.2: Scores for TE4 based on post-intervention CoRes.

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency				o	x			
2	Learner understanding				o	x			
3	Conceptual teaching strategies				o	x			
4	Representations			x	o				

4.5.2.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the big idea of MF and in response to question 1.1, shown in figure 4.4.11, the teacher mentioned that it was imperative for her learners to be able to define magnetic field strength and magnetic flux. Stating the physical significance of each symbol in the flux formula and performing some calculations using the magnetic flux formula were mentioned. The teacher mentioned that she wanted her learners to understand the concept of MF from graphical relationships between flux and field strength, loop area, and angle. Furthermore, she mentioned in her response to question 1.1 that relative motion was another necessary concept to be taught to learners, without which learners will have a restricted understanding of the concept of induction.



PCK Components	First Big Idea Magnetic flux---------------------------------:	Second Big Idea Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	• Definition of magnetic field strength and magnetic flux • Stating the physical meaning of symbols in the flux formula. • Differentiate between magnetic flux and field strength. • Differentiate between flux (ϕ) symbol and angle (θ) symbol, • Perform calculations using the magnetic flux formula, $\phi = B\cos\theta A$ • Differentiate between flux and flux change • Present graphical relationships between (1) flux and field strength (2) flux and loop area (3) flux and angle	• State Faraday's law in words • Interpret the physical meaning of each symbol in Faraday's formula. • Perform some calculations based on Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ $= \frac{-N(B_f \cos\theta A - B_i \cos\theta A)}{\Delta t}$ • Recall the significance of relative motion. during electromagnetic induction. • Provide factors necessary to increase emf output.

Figure 4.4.11: Snapshot of TE4’s post-CoRe responses to question 1.1 regarding her knowledge of curricular saliency for MF (left) and FL (right). Source: Researcher’s own.

In her response to question 1.2, shown in figure 4.4.12, the teacher mentioned learner background knowledge based on magnetic flux as vital for their proper understanding of the second big idea of FL. In her response to question 1.3, shown in figure 4.4.12, she cited the following as knowledge to be taught prior to teaching MF:

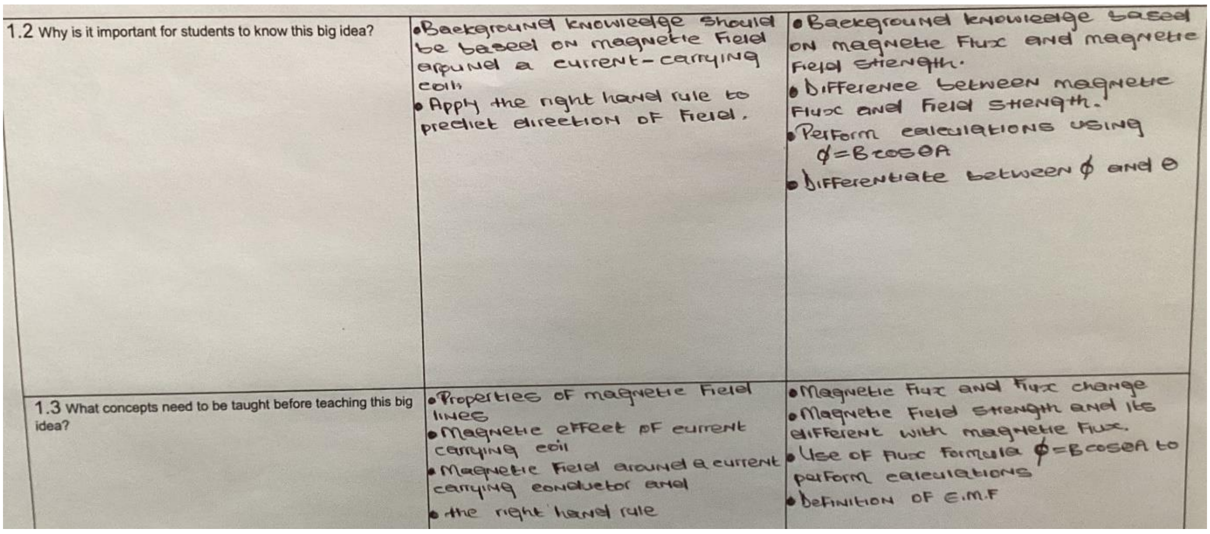
- Properties of magnetic field lines.
- Magnetic effect of current-carrying coil.
- Magnetic field around a coil carrying conductor and through a solenoid.

While responding to question 1.2, the teacher used the second column to mention the difference between magnetic flux and field strength, as well as the difference between the symbols for flux and angle, change in magnetic flux and the angle θ. This column was actually meant for the second key idea of FL.

The teacher's pPCK for this component based on the first big idea of MF after the intervention was therefore scored as '*developing*'. This score is justified by the fact that 'appropriate main idea(s) other than the headings in the CAPS document are included and there are indications that attention was paid to sequencing of the ideas', as stated in the rubric. Furthermore, the 'subordinate ideas that account for the application of equations and definitions are identified', as stated by the rubric.

For the second big idea of FL, while responding to question 1.1 for FL, shown in figure 4.3.11, the teacher suggested stating Faraday's law, symbol interpretation, numerical calculations, RHR application and EMF optimisation as part of her CS. However, in her response to question 1.1, and elsewhere, the teacher did not mention the application of the RHR to determine the direction of induced magnetic field and Lenz's law to predict the direction of the induced current. The teacher mentioned the importance of relative motion but did not explicitly specify where or between which components relative motion will be experienced. Furthermore, the significance of flux change and rate of flux change for induction of EMF was not mentioned.

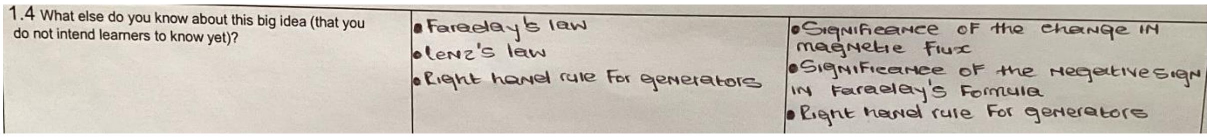
She did not answer question 1.2 for FL as she used that space for MF, as explained above. In her response to question 1.3 for FL, shown in figure 4.4.12, magnetic flux and calculations based on flux formula were cited as concepts which needed to be taught before introducing FL.



1.2 Why is it important for students to know this big idea?	• Background knowledge should be based on magnetic field around a current-carrying coil • Apply the right hand rule to predict direction of field.	• Background knowledge based on magnetic flux and magnetic field strength. • Difference between magnetic flux and field strength. • Perform calculations using $\phi = B\cos\theta A$ • Differentiate between ϕ and θ
1.3 What concepts need to be taught before teaching this big idea?	• Properties of magnetic field lines • Magnetic effect of current carrying coil • Magnetic field around a current carrying conductor and • the right hand rule	• Magnetic flux and flux change • Magnetic field strength and its different with magnetic flux. • Use of flux formula $\phi = B\cos\theta A$ to perform calculations • Definition of E.M.F

Figure 4.4.12: Snapshot of TE4's post-CoRe responses to question 1.2 and 1.3 regarding her knowledge of curricular saliency for MF (left) and FL (right). Source: Researcher's own.

In her response to question 1.4 written in the column for MF, shown in figure 4.4.13, she shows knowledge of progression citing Faraday's law, Lenz's law and the RHR for generators as part of what she knows and yet to be known by her learners.



1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	• Faraday's law • Lenz's law • Right hand rule For generators	• Significance of the change in magnetie Flux • Significance of the negative sign in Faraday's Formula • Right hand rule For generators

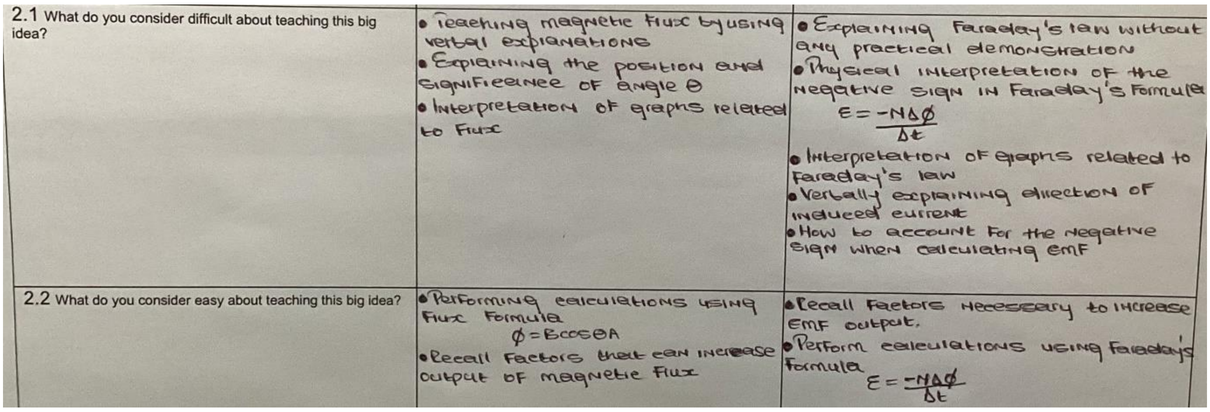
Figure 4.4.13: Snapshot of TE4's post-CoRe responses to question 1.4 regarding her knowledge of curricular saliency for MF (left) and FL (right). Source: Researcher's own.

The teacher responded to question 1.4 based on FL, shown in figure 4.4.13, mentioning that the physical significance of the change in flux and negative sign in Faraday's formula as something which she did not want her learners to know yet. However, this was in contradiction with the CAPS syllabus as the negative sign relates to the direction of induced current that information needed to be taught to Grade 11 learners. The teacher mentioned the RHR for generators as part of what she knows which she was not yet willing to make known to her learners. This was in agreement with the CAPS syllabus which requires that learners be taught generators only in Grade12.

The teacher's pPCK for this component based on the first big idea of FL after the intervention was therefore scored as '*adequate*'. This score is justified by the fact that 'identified concepts refer to elementary concepts generally regarded as basic to the subject or topic' as stated in the rubric. However, the 'reasons provided exclude considerations such as scaffolding / sequential development' as stated in the rubric. Important sub-ordinate ideas were not mentioned, and she did not answer question 1.2 for FL.

4.5.2.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, shown in figure 4.4.14, in her response to question 2.1, the teacher indicated that teaching magnetic flux is difficult. The teacher mentioned that angle is difficult to explain and that learners find it difficult to interpret graphs. Recall of definitions such as magnetic field strength and magnetic flux was considered as easier to teach.



2.1 What do you consider difficult about teaching this big idea?	• Teaching magnetic flux by using verbal explanations • Explaining the position and significance of angle θ • Interpretation of graphs related to flux	• Explaining Faraday's law without any practical demonstration • Physical interpretation of the negative sign in Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ • Interpretation of graphs related to Faraday's law • Verbally explaining direction of induced current • How to account for the negative sign when calculating emf
2.2 What do you consider easy about teaching this big idea?	• Performing calculations using flux formula $\phi = BcosθA$ • Recall factors that can increase output of magnetic flux	• Recall factors necessary to increase emf output. • Perform calculations using Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$

Figure 4.4.14: Snapshot of TE4’s post-CoRe responses regarding learner understanding for MF (left) and FL (right). Source: Researcher’s own.

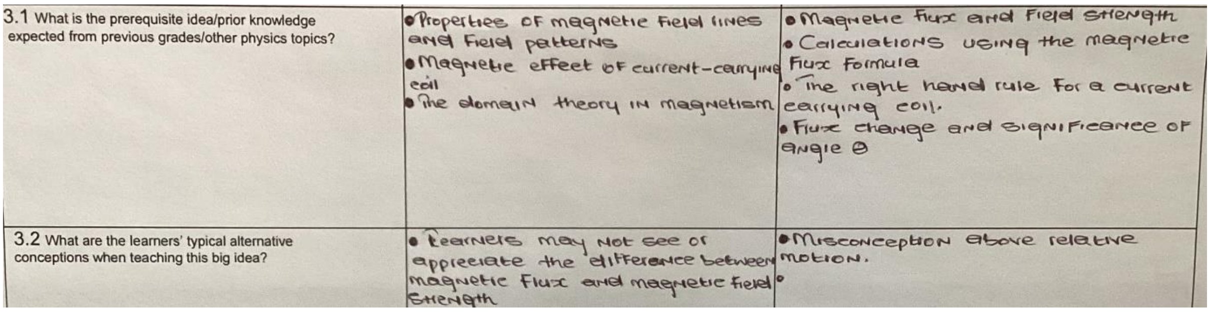
In response to question 3.1, shown in figure 4.4.15, the teacher cited properties of magnetic field lines and field patterns as prerequisite for learners to understand the flux concept. The teacher mentioned the magnetic effect of a current carrying coil as knowledge of learners prior to being exposed to the big idea of MF

However, the teacher made no mention of the magnetic field strength as a concept which needed to be addressed prior to teaching magnetic flux. Furthermore, the teacher cited the tendency by learners to view magnetic field strength and magnetic flux as one and the same thing as a possible source of alternative conception.

The teacher’s pPCK for this component based on the MF after the intervention was therefore scored as ‘*developing*’. This score is justified by the fact that ‘appropriate difficulties for two of the main ideas are identified and clearly formulated’, as stated in the rubric.

For the second big idea of FL, the teacher mentioned in the second column of figure 4.4.14 that the physics related to the direction of the induced current and graphs interpretation was difficult. She mentioned that teaching without practical and the physical significance of the negative sign in the formula was just as difficult.

Shown in figure 4.4.15, she mentioned flux, flux calculations, the flux change, RHR and the physical significance of the angle, as the necessary knowledge needed by learners prior to their being exposed to the big idea of FL. In her response to question 3.2, the teacher mentioned relative motion as a source of misconception by learners. It is not clear what exactly she thinks may be misunderstood.



3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	• Properties of magnetic field lines and field patterns • Magnetic effect of current-carrying coil • The domain theory in magnetism	• Magnetic flux and field strength • Calculations using the magnetic flux formula • The right hand rule for a current carrying coil. • Flux change and significance of angle θ
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	• Learners may not see or appreciate the difference between magnetic flux and magnetic field strength	• Misconception above relative motion. •

Figure 4.4.15: Snapshot of TE4's post-CoRe responses regarding *learner understanding* for MF (left) and FL (right). Source: Researcher's own.

The teacher's pPCK for this component based on the second big idea after the intervention was therefore scored as 'adequate'. This score is justified by the fact that 'an appropriate difficulty related to one of the main ideas is identified and clearly formulated', as stated in the rubric. Although the teacher twice mentioned the negative sign in Faraday's Law as a difficulty, she made no mention of whether the application of the RHR and predicting the direction of the induced current was difficult or easy to teach, which can be considered as gate-keeping ideas for the understanding of FL.

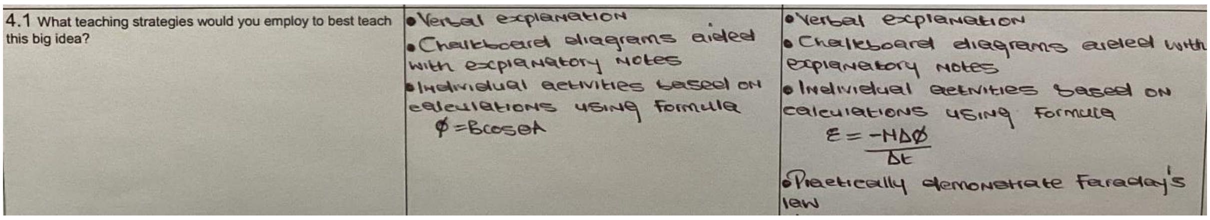
4.5.2.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF shown in figure 4.4.16, the traditional verbal explanatory approach was mentioned as part of her CTS. Chalkboard diagrams aided by some explanatory notes were suggested as part of CTS to assist learners in conceptualising magnetic flux. The teacher suggested some individual activities based on calculations using the magnetic flux formula as a CTS to enable learners to independently solve problems. While responding to question 4.2, shown in figure 4.4.17, the teacher suggested questions related to definitions, and relationship concepts. The teacher did not mention anything about the angle.

However, since the teacher knew that the learners struggle to understand the difference between magnetic field and magnetic flux (response to question 3.2 figure 4.4.16), one expected her to have a conceptual teaching strategy ready to support conceptual development. This, however, was not the case.

The teacher's pPCK for this component based on the big idea of MF after the intervention was scored as '*developing*'. This is because the 'overall strategy is workable and at least one aspect related to curriculum saliency or sequencing is considered' as stated in the rubric, but there is no 'evidence that the CTS will support conceptual understanding' of all the subordinate ideas.

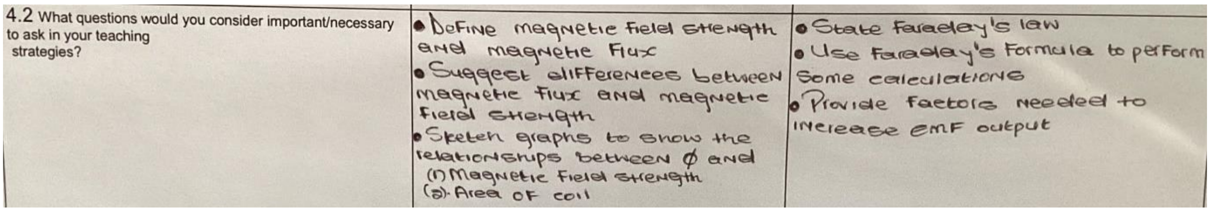
For the second big idea of FL shown in figure 4.4.16, the teacher suggested the traditional verbal explanatory approach and chalkboard diagrams aided by some explanatory notes and practical demonstration as effective CTS for treating Faraday’s law. The teacher suggested some individual activities based on calculations using Faraday’s formula as a CTS to enable learners to independently solve problems.



4.1 What teaching strategies would you employ to best teach this big idea?	• Verbal explanation • Chalkboard diagrams aided with explanatory notes • Individual activities based on calculations using formula $\phi = B\cos\theta A$	• Verbal explanation • Chalkboard diagrams aided with explanatory notes • Individual activities based on calculations using formula $\mathcal{E} = \frac{-N\Delta\phi}{\Delta t}$ • Practically demonstrate Faraday's law

Figure 4.4.16 Snapshot of TE4’s post-CoRe responses to question 4.1 regarding her CTS for MF (left) and FL (right). Source: Researcher’s own.

While responding to question 4.2 based on FL, shown in figure 4.4.17, the teacher suggested questions related to stating Faraday’s law. numerical calculations, RHR application and EMF optimisation.



4.2 What questions would you consider important/necessary to ask in your teaching strategies?	• Define magnetic field strength and magnetic flux • Suggest differences between magnetic flux and magnetic field strength • Sketch graphs to show the relationships between ϕ and (1) Magnetic field strength (2). Area of coil	• State Faraday's law • Use Faraday's formula to perform some calculations • Provide factors needed to increase emf output

Figure 4.4.17: Snapshot of TE4’s post-CoRe responses to question 4.2 regarding her CTS for MF (left) and FL (right). Source: Researcher’s own.

However, the teacher did not mention how she will assist learners to predict the direction of the induced current. Furthermore, the teacher did not mention how she will teach learners to apply the RHR and to interpret the negative sign in Faraday’s formula.

The teacher’s pPCK for this component based on the big idea of FL after the intervention was therefore scored as ‘*adequate*’. This is because ‘The response lacks aspects of curriculum saliency’ and there is ‘insufficient conceptual development’, as stated in the rubric. Furthermore, ‘there is no evidence of acknowledgement of student prior knowledge and misconceptions’, as stated in the rubric.

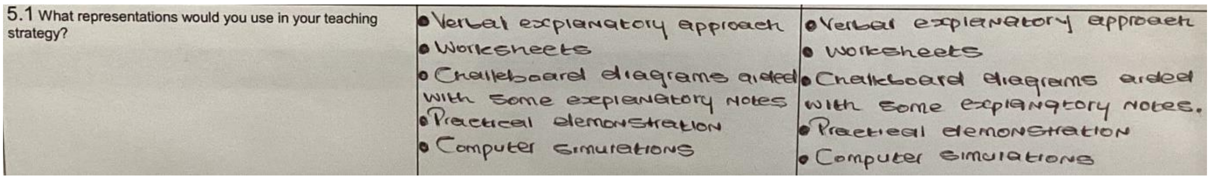
4.5.2.4 REPRESENTATIONS

For the first big idea of MF, shown in figure 4.4.18, she mentioned the traditional verbal explanatory approach, worksheets and chalkboard diagrams aided by some explanatory notes as representation to be adopted during lesson execution. Furthermore, the teacher proposed to represent MF using practical demonstration and computer simulations.

However, the teacher did not go further to elaborate on the kind of experiment she would carry out to demonstrate the concept of flux. Furthermore, worksheets (as mentioned by the teacher) cannot be considered as a representation.

The teacher’s pPCK for this component based on the first big idea of MF was scored as ‘*adequate*’ after the intervention. This is because ‘the selection of representations (visual or symbolic) is insufficient’ as stated by the rubric.

For the second big idea of FL, shown in figure 4.4.18, practical demonstration and computer simulations to represent Faraday’s law of electromagnetic induction were mentioned. Furthermore, she mentioned the traditional verbal explanatory approach, worksheets and chalkboard diagrams aided by some explanatory notes as representation to be adopted during lesson presentation.



5.1 What representations would you use in your teaching strategy?	• Verbal explanatory approach • Worksheets • Chalkboard diagrams aided with some explanatory notes • Practical demonstration • Computer simulations	• Verbal explanatory approach • Worksheets • Chalkboard diagrams aided with some explanatory notes. • Practical demonstration • Computer simulations

Figure 4.4.18: Snapshot of TE4’s post-CoRe responses regarding her representation for MF (left) and FL (right). Source: Researcher’s own.

However, worksheets (as mentioned by the teacher) cannot be considered as a representation for the big idea of FL. She did not suggest any representation to explain the direction of current. Hence, the teacher’s pPCK for this component based on the second big idea of FL was scored as ‘*adequate*’. This is because ‘there is no evidence how the use of the representation will lead to increased understanding of concepts’ as stated in the rubric.

4.5.3 COMPARISON OF TE4’s PRE- and POST-INTERVENTION CoRes

The scores for each PCK component from tables 4.4.1 and 4.4.2 are compared in order to gain an overall impression of whether the scoring levels have improved following the intervention. Table 4.4.3 shows a summary of these scores.

Table 4.4.3 Summary of TE4's pre- and post-intervention personal PCK scores.

PCK Components	**PCK Scoring level summary**															
	PRE-CoRe								**POST-CoRe**							
	L		**A**		**D**		**E**		**L**		**A**		**D**		**E**	
	MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
Curricular Saliency			x	o								o	x			
Learner understanding			x	o								o	x			
Conceptual teaching strategies			x	o								o	x			
Representations		o	x								x	o				

From table 4.4.3, the immediate observation is that there was a small shift in PCK scores. The PCK for pre-intervention CoRes were prevalently dominated with an *adequate* score. The same was observed for the post intervention CoRe. However, there were some small shifts in some specific PCK components. The post-CoRe scores highlighted in yellow indicate which scores improved after the intervention compared to pre-CoRe scores. This gives the general impression that the intervention had a very small impact on the way TE4 constructed her post-intervention CoRes.

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in table 4.1.4. Table 4.4.4 shows the comparative PCK scores on a numerical scale.

Table 4.4.4: Summary of TE4's comparative PCK scores on a scale ranging from 1 to 4.

PCK Components	**Scores**					
	Pre-CoRe			**Post-CoRe**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular saliency	2	2	2.0	3	2	2.5
Learner understanding	2	2	2.0	3	2	2.5
Conceptual teaching strategies	2	2	2.0	3	2	2.5
Representations	2	1	1.5	2	2	2.0
Total (16)	8	7	7.5	11	8	9.5
Average (4)	2.0	1.8	1.9	2.8	2.0	2.4

There was a noticeable difference between pre-CoRe scores and post-CoRe scores based on the big idea of MF. The scores increased by an average of 0.8 points (from a score of 2.0 to 2.8). There was a very minor difference between the pre-CoRe scores and post-CoRe scores that was observed based on the second big idea of FL. The scores increased by an average of 0.2 points (from a score of 1.8 to 2.0) after the intervention. Combining the two big ideas, the overall average score increased by 0.5 points (from 1.9 for pre-CoRe to 2.4 for post-CoRe). There is some evidence indicating that the intervention had an impact in the way the teacher constructed her CoRes based on MF prior to teaching it. However, there was no convincing evidence to warrant the conclusion that the intervention had an impact in the way TE4 constructed her CoRes based on FL prior to teaching it.

4.5.4 VIDEO-RECORDED LESSON OBSERVATIONS: THE CASE OF TE4.

The transcript of the video-recorded lesson is available in Appendix D4. Four sections were identified from teacher TE4's lesson. Having not taught Grade 11 before, it was her first time to encounter the concept of MF and FL as an in-service teacher. TE4 managed to teach both the first and second big ideas of MF and FL in just one lesson. The lesson was video-recorded from the back of the classroom in the presence of the researcher. The entire lesson took 60min 54sec.

Section 1: Introduction [3 min 22 sec]

In her introduction, TE4 began with a brief reflection of the previous lesson's ideas based on magnetic field around a straight conductor and solenoid carrying current. The reflection reminded learners that a current through a conductor induces a magnetic field around a conductor. In her introduction, she mentioned the right-hand rule and its application in predicting direction of the magnetic field.

Section 2: Teaching the big idea of magnetic flux [25min 05sec]

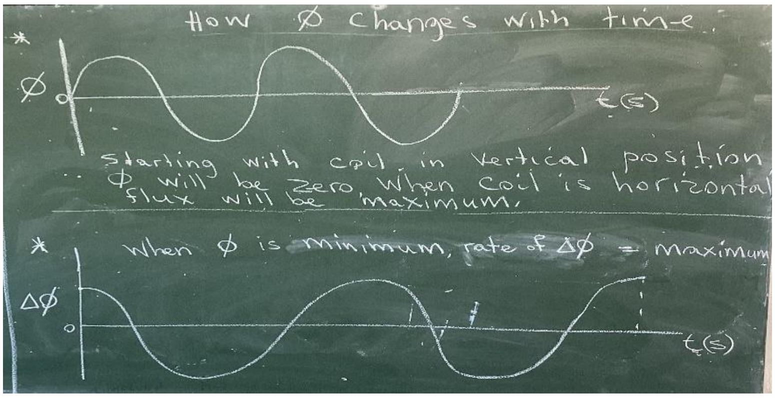
TE4 introduced the new concept of magnetic flux. In her introduction she verbally defined magnetic flux as:

"….magnetic flux is a product of loop area and component of magnetic field strength.

However, she did not elaborate whether the component was vertical or horizontal. She then wrote the statement of MF definition on the chalkboard as shown in figure 4.4.19.

Figure 4.4.19: Screenshot showing TE4 using chalkboard notes to explain magnetic flux. Source: Researcher’s own.

The mathematical expression of magnetic flux was written on the chalkboard and the physical meaning of each symbol was explained. She verbally explained the difference between magnetic field strength and magnetic flux. The teacher went further to draw some graphs on the chalkboard, shown in figure 4.4.20, and used them to show how flux changes when a loop rotates in a magnetic field.


How Ø changes with time.

∴ Starting with coil in vertical position Ø will be zero. When coil is horizontal flux will be maximum.

When Ø is minimum, rate of ΔØ = maximum

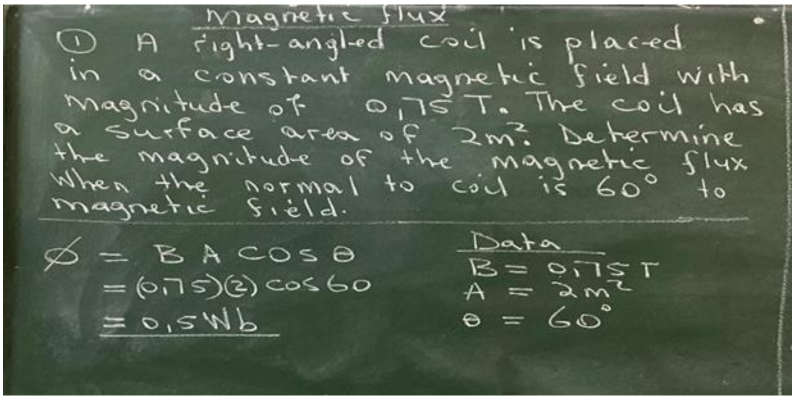
Figure 4.4.20: Snapshot showing graphs used to explain the difference between flux and flux change. Source: Researcher’s own.

In her explanation she said:

Please observe from the graphs that when coil is vertical flux change is maximum and flux will be zero. When coil is horizontal, flux is maximum and the change in flux will be zero.

However, in her explanation, she did not mention that the angle changes during rotation. Furthermore, she did not relate vertical and horizontal to the angle between the loop and field.

She presented an example on the chalkboard based on flux formula as shown in figure 4.4.21.



Magnetic flux

① A right-angled coil is placed in a constant magnetic field with magnitude of 0,75 T. The coil has a surface area of 2m². Determine the magnitude of the magnetic flux when the normal to coil is 60° to magnetic field.

$\emptyset = B A \cos\theta$

$= (0{,}75)(2) \cos 60$

$= 0{,}5 \text{ Wb}$

Data

$B = 0{,}75 \text{ T}$

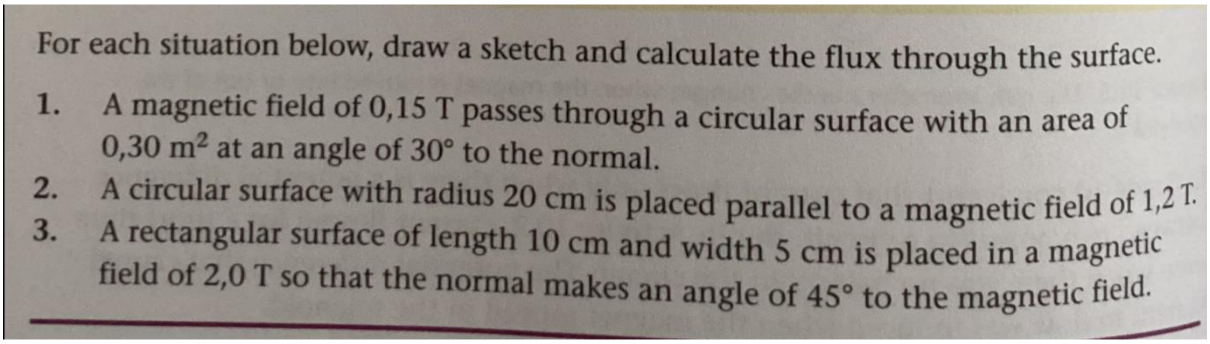
$A = 2 \text{m}^2$

$\theta = 60°$

Figure 4.4.21: Snapshot showing a chalkboard calculation based on flux formula. Source: Researcher’s own.

However, she did not emphasise on the significance of the angle while she presented her example shown in figure 4.4.21.

She then asked the learners some questions shown in figure 4.4.22 based on calculation of magnetic flux from the worksheet. Learners were requested to individually attempt answering the questions.



For each situation below, draw a sketch and calculate the flux through the surface.

1. A magnetic field of 0,15 T passes through a circular surface with an area of 0,30 m^2 at an angle of 30° to the normal.
2. A circular surface with radius 20 cm is placed parallel to a magnetic field of 1,2 T.
3. A rectangular surface of length 10 cm and width 5 cm is placed in a magnetic field of 2,0 T so that the normal makes an angle of 45° to the magnetic field.

Figure 4.4.22: Snapshot showing a question asked of learners as individual class activity based on MF. Source: Researcher’s own.

While the learners were busy responding to the questions in their classwork books, TE4 moved around monitoring progress and assisting individual learners. A feedback based on the magnetic flux classwork was then given in which the solutions to the questions were discussed.

<u>Section 3: </u>Teaching the second big idea of Faraday's law [28min 10sec]

The teacher verbally introduced Faraday's law of electromagnetic induction while linking it with the first big idea of magnetic flux. In her introduction, she said:

The main reason why we had to start by dealing with magnetic flux and some calculations using the flux formula is because Faraday's law deals with change in magnetic flux. The numerator part of Faraday's formula contains a change in magnetic flux.

However, she made no mention of the meaning of 'induction' while treating the big idea of FL. She then wrote Faraday's mathematical formula on the chalkboard and explained the physical significance of each symbol in the formula. She did not explain the physical significance of the negative sign in Faraday's formula. Instead, she simply said:

…*I think you can see a negative sign in the formula. This is the only formula I know of in physics which has a negative sign in it. So please when using this formula, don't forget that there is a negative sign.*

However, the negative sign seemingly posed some challenges for the teacher to explain to her learners. In her explanation of the physical meaning of the negative sign she should have mentioned the 'current direction is such as to oppose the cause of induction'.

She then wrote the statement of Faraday's law on the chalkboard after explaining symbols in the formula as shown in figure 4.4.23.

Figure 4.4.23: Screenshot showing TE4 using chalkboard notes to explain Faraday's law. Source: Researcher's own.

During the lesson, one of her learners questioned the origin of the negative sign in Faraday's formula. The teacher confidently responded saying:

Don't worry about the negative sign. Just don't forget to include it when you are performing your calculations because it's part of Faraday's formula.

The learner who asked the question was seemingly not convinced with the teacher's response. Fortunately, another learner came to her rescue in giving an explanation pertaining the negative sign:

I think the negative sign has to do with the direction of the induced current which can also be predicted by using Lenz's law.

The teacher acknowledged the learner's explanation and even requested the class to clap hands for him.

The teacher then verbally explained the ways that can be used to increase the magnitude of the induced EMF. Some graphs such as the one in figure 4.4.24, were presented on the chalkboard to aid her explanations.

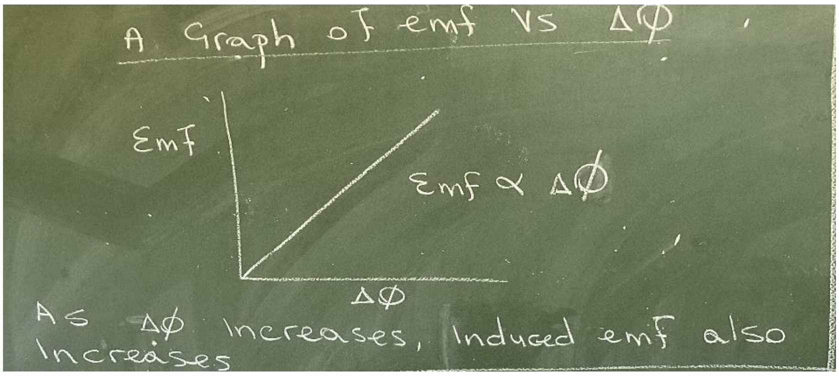


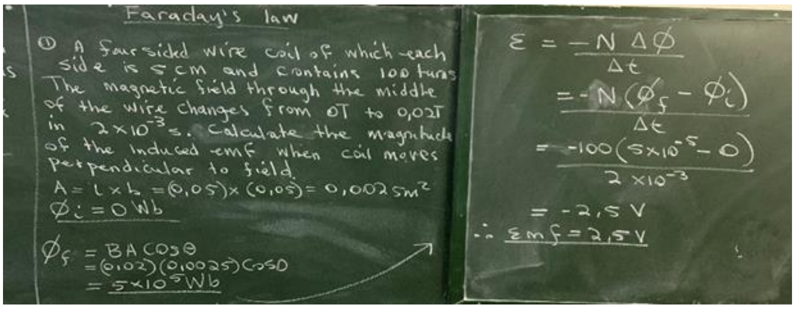
Figure 4.4.24: Snapshot showing graph used to explain the relationship between EMF and flux change. Source: Researcher's own.

However, there was an error in the graph. The horizontal axis should be for RATE of change of flux, $\Delta\varnothing/\Delta t$.

While presenting graphs she placed more emphasis on the importance of flux change in Faraday's law:

As you can see from this graph that an increase in flux change consequently leads to an increase in emf. This means that what matters most for emf to be induced in the coil is not just the magnetic flux but the change in magnetic flux.

However, her explanation is not correct. Instead of talking about rate of change of flux, she talked about change of flux. So, she misrepresented an important subordinate idea. The teacher then gave learners an example on the chalkboard of a numerical calculation using Faraday's formula as shown in figure 4.4.25.



Faraday's law

① A four sided wire coil of which each side is 5 cm and contains 100 turns The magnetic field through the middle of the wire changes from 0T to 0,02T in 2×10^{-3} s. Calculate the magnitude of the induced emf when coil moves perpendicular to field.

$A = l \times b = (0{,}05)\times(0{,}05) = 0{,}0025\,m^2$

$\phi_i = 0\,Wb$

$\phi_f = BA\cos\theta$
$= (0{,}02)(0{,}0025)\cos 0$
$= \underline{5\times10^{5}\,Wb}$

$$\varepsilon = \frac{-N\Delta\phi}{\Delta t}$$
$$= \frac{-N(\phi_f - \phi_i)}{\Delta t}$$
$$= \frac{-100(5\times10^{-5} - 0)}{2\times10^{-3}}$$
$$= -2{,}5\,V$$
$$\therefore \underline{emf = 2{,}5\,V}$$

Figure 4.4.25: Snapshot showing a chalkboard example of calculation based on Faraday's formula. Source: Researcher's own.

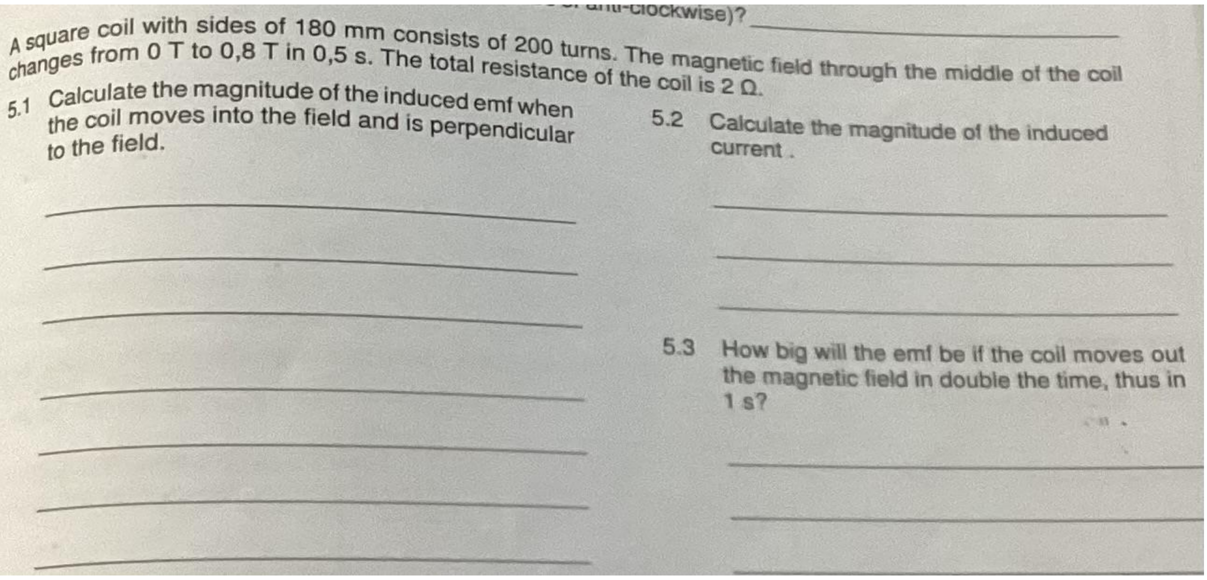
In her presentation, she placed emphasis on the importance of understanding the concept of magnetic flux but once again referred to change in flux instead of rate of change in flux when dealing with Faraday's law:

Please note that it is of paramount importance for us to first calculate the change in magnetic flux which also forms the numerator part of Faraday's formula.

Furthermore, she placed emphasis on ignoring the negative sign in the final solution when calculating induced EMF:

I think you can all realise that our final solution to the numerical problem on the chalkboard has a negative sign. So, in this case we ignore it and eventually present it as shown on the chalkboard. This is because our interest is only based on the magnitude of the induced emf.

She then asked the learners some practice questions to attempt as individuals in their classwork books. Figure 4.4.26 shows one of the questions selected from the learners' worksheet.



anti-clockwise)?

A square coil with sides of 180 mm consists of 200 turns. The magnetic field through the middle of the coil changes from 0 T to 0,8 T in 0,5 s. The total resistance of the coil is 2 Ω.

5.1 Calculate the magnitude of the induced emf when the coil moves into the field and is perpendicular to the field.

5.2 Calculate the magnitude of the induced current .

5.3 How big will the emf be if the coil moves out the magnetic field in double the time, thus in 1 s?

Figure 4.4.26: Snapshot showing a question asked of learners as individual class activity based on FL. Source: Researcher's own.

While the learners were busy with the question that she had assigned to them, she moved around checking whether they were doing it right. She came to realise that most of her learners were having a challenge with question 5.2. The question required them to calculate the magnitude of the induced current. She then went on to guide learners on the relevant formula to use which she wrote on the chalkboard.

Here in 5.2, we make use of this formula which is associated with Ohm's law. So, since we are given resistance and we have just calculated the magnitude of the induced emf, it's easy to determine the size of the induced current.

Section 4: Conclusion [4min 17sec]

TE4 then concluded the lesson by briefly summarising the entire lesson and mentioning the application of EMI in electricity generation. She gave her learners further practise questions based on both magnetic flux and EMF. The questions involved, definitions, distinctions, graphical interpretations, and numerical calculations.

4.5.5 TEACHER TE4'S VSRI RESPONSES.

The transcript of the video stimulated recall interview (VSRI) session is available in Appendix E4. The VSRI session was held at TE4's school a day after conducting the video-recorded lesson observation. The VSRI provided more insight into how the teacher enacted her PCK. While responding to a question based on her personal impression regarding video-recorded lesson observations, the teacher acknowledged that:

It is quite imperative for me as an educator to video record and play back my lessons. This provides me with quick evidence-based way of reflecting on my lesson. this will further assist me to grow professionally as I will be able to develop better teaching strategies.

During the VSRI session the teacher was requested to provide a comment regarding her overall impression of the lesson after watching the video of herself teaching. In her response she indicated that:

I think I tried my best to present the lesson based on magnetic flux and Faraday's law. This was my first time to be teaching this section to the grade 11s. I managed to explain to them what magnetic flux is and how it is linked to change in magnetic flux and Faraday's law. I also explained the meaning of all the symbols that are used in both formulas for flux and for Faraday's law. I also gave them typical examination questions as examples as well as classwork activities. I actually treated all the bullets as expected by both the examination guidelines and CAPS syllabus.

However, her lesson appeared to be passive as there were no practical activities for learners or even some simulated videos for learners to watch. Furthermore, she did not 'treat all the bullets' in the CAPS syllabus. She completely avoided the direction of the current.

The teacher could be seen doing most of the talking. A question was asked as to whether the teacher was satisfied with the conceptual teaching strategies which she had employed while teaching both magnetic flux and Faraday's law. In her response she mentioned:

Not at all. I think that is where I could have done better by perhaps doing a simple demonstration based on electromagnetic induction. But due to the lack of necessary laboratory apparatus, doing a demonstration was not possible. Maybe perhaps I could have used my own personal laptop to show some simulations or simulated videos related to magnetic flux and Faraday's law. Unfortunately, I don't have any videos or simulations related to the entire section of electromagnetism.

It's evident from her explanation that she lacks knowledge of ICT tools for pedagogical purposes. She apparently does not know how many videos and simulations are freely available on the Internet. When asked to comment about the challenges she might have faced which led her to change her CTS and representation during actual teaching from what she suggested in her post-CoRes, she responded saying that:

Yes, I actually thought that I was going to be able to conduct the experiment to demonstrate the concept of magnetic flux and Faraday's law. But I only realised when I was about to begin with this section that we don't have the necessary laboratory equipment even for a *simple demonstration. I even tried to borrow some lab equipment related to this section from my neighbouring school. But the teacher was unable to give me since she was also busy with the same section with her learners. That is why I ended up doing it this way.*

The VSRI session confirmed some gaps which were noticed in her lesson presentation. These gaps compromised the level of her PCK enactment. During the VSRI session, a challenge related to the teacher's understanding of content and curriculum was noticed. It was during the VSRI session that the teacher first acknowledged her lack of understanding of Lenz's law as noted in her failure to explain the origin of the negative sign in Faraday's formula.

Firstly, in the video play back (VPB) of the lesson, the teacher was saying:

VPB-1"…*I think you can see a negative sign in the formula. This is the only formula I know of in physics which has a negative sign in it. So please when using this formula, don't forget that there is a negative sign.*

When requested during the VSRI session to comment on her explanation regarding the negative sign in Faraday's law she said:

Honestly speaking I didn't know what to tell my learners about the negative sign, but I had to say something. I prayed that no one asks about the origin of the negative sign but unfortunately one of my learners ended up asking.

Indeed, the teacher was very honest by admitting her shortcomings. From the video playback, another learner from her class whose hand was raised, requested to assist in giving an explanation pertaining the negative sign. The learner was noted byTE4 and given the chance and in his explanation, he said:

VPB-2 *I think the negative sign has to do with the direction of the induced current which can also be predicted by using Lenz's law.*

When requested to comment on the learner's response during the VSRI session she said:

…….I felt so relieved, and I had to acknowledge that learner's explanation which I also needed the most and that is why I even requested the class to clap hands for him.

Instead of the teacher to predicate on the learner's explanation by perhaps paraphrasing it, she chose not to elaborate. This negatively impacted on her PCK enactment. Her reaction reveals that she probably does not know how Lenz's law works.

When a question pertaining the stance of CAPS syllabus on direction of induced current was asked of the teacher, she responded:

Yes, in the CAPS document, there is a bullet about direction of the induced current. I have always been wondering to myself how this could possibly be done. But I now understand what that bullet was implying. But at least it could have easily been interpreted if they had explicitly stated it as Lenz's law.

While responding to a question on areas which needed her immediate attention to make her teaching of magnetic flux and Faraday's law to be better she said:

I think my conceptual teaching strategies were very poor as well as their associated representations. I should have done much better by perhaps blending my explanations of concepts with simulations or videos from the internet. I wanted to quickly cover this section of the annual teaching plan but at the expense of my learners.

Her honest responses during the VSRI session aided by evidence from video recordings, suggest that her presentation was completely focused on algebraic problem-solving. There was no link to the physical reality of induction.

4.5.6 SEMI-STRUCTURED INTERVIEW RESPONSES

The transcript of the semi-structured interview (SSI) session is available in Appendix F4. An SSI session was conveniently carried out at TE4's school and in her quiet office, after school hours to avoid disrupting her lessons and other school programmes. The SSI session was carried out three days after the video-recorded EMI lesson observation. The entire SSI session lasted for twenty-seven minutes.

During the SSI session, she responded to all the questions asked of her. The entire SSI session was audio-recorded with the teacher's permission. Some of the teacher's responses during the SSI session were like those given during the VSRI session. Therefore, in this section the discussions shall only be centred on responses that are not a repetition of the VSRI responses.

When a question pertaining her experience in teaching the Grade 11 section of electromagnetic induction was asked of her, she said:

Honestly speaking, I have never taught this section in my entire career. In fact, this is my first year to be teaching the grade 11 learners. I have actually come to realise that there is a lot involved in the teaching of electromagnetic induction. Like just telling learners what happens without any form of demonstration will not make any sense to them.

During the SSI session, the teacher acknowledged her own misunderstanding of Lenz's law and about the application of the RHR.

Researcher: If you were to score yourself out of 10, what score would you give yourself in so-far as your understanding of CAPS syllabus is concerned?

The teacher's response was:

I wouldn't give myself 10 out 10, neither would I give myself 3 out of 10. Perhaps I would score myself with a 6 out of 10. There are a lot of bullets in the Physical Sciences CAPS document, most of which require interpretation aided by other sources like textbooks and examination guidelines. I am still in the process of trying to understand the expectations of the CAPS syllabus.

While responding to a question based on what strategies and representations, she would employ if given a chance to re-teach magnetic flux and Faraday's law she said:

It's just that my school is very poorly resourced when it comes to lab equipment. I could have done some experiments with the learners. But net time I think I will have to download some pre-selected internet videos based on magnetic flux and Faraday's law. The videos will assist me to explain the concepts easily, i think.

4.5.7 SCORING ENACTED PCK for TE4

In this section, the researcher links what transpired during the lesson observation with the teacher's VSRI and SSI aftermath responses to evaluate her enacted PCK. The scores were assigned to each of the specific PCK components based on the video recordings of the lesson observations and after the VSRI and SSI sessions with the teacher. Table 4.4.5 presents these scores. Following the table, discussions are presented to illustrate how the scores were allocated for the PCK components.

This discussion focuses on interesting aspects of TE4's PCK enactment in view of the selected key ideas in her CoRes.

Table 4.4.5: Scores of TE4 based on enacted PCK

PCK Components		**PCK Scoring levels**							
		Limited		**Adequate**		**Developing**		**Exemplary**	
		MF	**FL**	**MF**	**FL**	**MF**	**FL**	**MF**	**FL**
1	Curricular saliency		o			x			
2	Learner understanding		o	x					
3	Conceptual teaching strategies		o	x					
4	Representations		o	x					

4.5.7.1: KNOWLEDGE OF CURRICULAR SALIENCY

For the first big idea of MF, the teacher presented the definition of magnetic flux to her learners. She then wrote the magnetic flux formula on the chalkboard and verbally explained the physical meaning of symbols in the flux formula. An example of how to calculate using magnetic flux formula was presented and verbally explained while making use of the chalkboard as shown in figure 4.4.21. The teacher presented some graphs on the chalkboard showing the relationships between the change in magnetic flux and time. For each graph the teacher verbally explained and wrote some explanatory notes as shown in figure 4.4.20. While responding to a question during the VSRI session based on whether she managed to achieve what she had planned she responded:

I think I did my best, even the graphs that I have use to assist learners in understanding the concept of the flux were quite relevant. I also went through an example with them which I presented on the chalkboard. I then gave them some questions to attempt as individuals based on the example and they did very well.

Consequently, her ePCK for this component based on MF was awarded a score of '*developing*'. This score is justified by the fact that 'there are indications that attention was paid to sequencing of the ideas', as stated in the rubric. Furthermore, 'there is evidence of knowledge about sequencing and scaffolding of concepts, and key ideas following the current key idea are included', as stated in the rubric. However, the 'list of subordinate ideas is not extensive'.

For the second big idea of FL, she verbally introduced Faraday's law and then wrote it on the chalkboard. The teacher then wrote Faraday's formula on the chalkboard and verbally explained the physical meaning of each symbol.

However, her explanation of the negative sign was not quite convincing. She had to be rescued by one of her learners who said it can be explained it in terms of Lenz's law. During the VSRI session the teacher indicated that:

…….I felt so relieved, and I had to acknowledge that learner's explanation which I also needed the most and that is why I even requested the class to clap hands for him.

It was clear that she avoided the subordinate idea of Lenz's law as she did not understand the law.

The teacher went on to give an example of how to perform a calculation based on Faraday's law. However, most of her learners had forgotten how current is calculated, hence, when she gave her learners some individual work to do, most of them could not calculate the question 5.2 part of the questionnaire shown in figure 4.4.26. Furthermore, the approach needed in calculating question 5.2 required learners' understanding of Grade 10 electric circuits which they had forgotten.

The teacher used graphs to explain the relationships between EMF and number of coil-turns, EMF and magnetic field strength, EMF and cross-sectional area of the loop, EMF and change in magnetic flux. However, one graph was wrong, using change of flux instead of rate of change of flux $\Delta\varnothing/\Delta t$. In fact, she did not mention the subordinate idea of rate flux change; instead, she emphasised flux change.

The teacher's ePCK for this component based on the big idea FL was therefore scored as '*limited*'. This is because 'main ideas are repeated/ restated without further development into subordinate ideas', as stated in the rubric. Furthermore, 'there is inadequate evidence of knowledge about sequencing', as stated in the rubric. Knowledge of the curriculum is not evident.

4.5.7.2 KNOWLEDGE OF LEARNER UNDERSTANDING

For the first big idea of MF, the teacher defined magnetic flux and magnetic field strength and verbally explained the difference between them, thus addressing an important learner difficulty. Verbal explanations as well as chalkboard explanatory notes were given. A class activity based on numerical calculations using flux formula was then given to the learners to attempt as individuals in order to assess their understanding of the MF concept.

However, no practical demonstration or video simulation was shown to learners, to aid in explaining the flux concept. Furthermore, the teacher made no mention of the prior knowledge needed for learners to understand the MF concept. When asked during the VSRI session the teacher indicated that she could not do any practical demonstration because her school was poorly resourced.

Besides, that I can't still imagine how such an experiment to demonstrate magnetic flux can be done even if we had equipment. Simulations are perhaps possible but unfortunately, I don't have any simulations or videos related to this entire section of EMI in my laptop.

In this case she spoke about difficulties with resources, not conceptual difficulties. However, she did address the challenge to distinguish between magnetic field and flux. She did not explain anything about the angle, an important subordinate idea in the flux concept.

The teacher's ePCK for this component based on the big idea MF was therefore scored as '*adequate*'. This is because 'an appropriate difficulty related to one of the main ideas is identified and clearly formulated', as stated in the rubric.

For the second big idea of FL, the teacher verbally introduced Faraday's law and wrote the statement of the law on the board. She then presented the formula on the chalkboard and explained the physical meaning of each symbol used in Faraday's formula. In her explanation, she tried to link the concept of MF with the second big idea of FL.

However, she experienced some challenges while explaining the significance of the negative sign in Faraday's formula. Furthermore, the teacher made no attempt to explain the direction of the induced current in terms of Lenz's law.

During the VSRI session she acknowledged that:

I felt so relieved, and I had to acknowledge that learner's explanation which I also needed the most. ……Because the explanation associated with the negative sign in Faraday' s formula has never been convincingly clear to me.

The teacher did not explain the significance of the RHR during electromagnetic induction.

The teacher's ePCK for this component based on the big idea FL was therefore scored as '*limited*'. This is because 'knowledge about this component is not evident. Main ideas are rephrased or restated, and 'broad topics without specifying the actual sub-concepts that are problematic are identified', as stated in the rubric.

4.5.7.3 CONCEPTUAL TEACHING STRATEGIES

For the first big idea of MF, the teacher used verbal explanations aided by some chalkboard notes and sketch graphs as a CTS to teach the concept of flux to her learners. The teacher then drew some graphs on the chalkboard and used them to clarify the difference between magnetic flux and flux change. She worked through an example of a question related to MF guiding learners on how to calculate flux and change in flux. During her verbal explanation she emphasised that:

There is difference between magnetic flux and magnetic field strength. But we are going to primarily focus especially on flux and change in magnetic flux.

However, the teacher made no attempt to draw a diagram and explain the physical significance of the angle. She mentioned the component during her introduction to MF saying:

……Magnetic flux is a scalar quantity. It is also a product of the component of magnetic flux density and area of the loop……

She did not elaborate by referring to the angle in the formula. During the VSRI session when requested to justify her approach, she said:

I am not that good in terms of drawing. Besides that, I thought that the learners would visualise the angle from the handouts which we used while dealing with the questions.

As part of her CTS, she asked some questions of her learners to guide them through the concept of MF. However, some of the questions could not trigger higher-order thinking skills. Instead, they promoted rote learning. For example:

So, who can define magnetic flux for us? What is magnetic flux?

Furthermore, the teacher made no attempt to use differentiated CTSs like making use of videos or video simulations to aid in her explanations while teaching MF.

The teacher's ePCK for this component based on the big idea MF was therefore scored as '*adequate*'. This is because 'the response lacks aspects of curriculum saliency', as stated in the rubric. The teaching strategies had limited explanation of application. Furthermore, the 'questions were basic and mostly rote learning questions are posed' and 'very little encourage of learner involvement' as stated in the rubric

For second big idea of FL the teacher used a teacher-centred verbal approach as a CTS to teach Faraday's law to her learners. The teacher presented Faraday's law statement together with its associated formula on the chalkboard and verbally explained it to her learners. Some sketch graphs each supported by explanatory notes were used as CTS to explain the relationship between induced EMF and change in magnetic flux, magnetic field strength, number of coil turns and cross-sectional area of the loop. This was explained using figure 4.4.24.

However, there was a mistake in figure 4.4.24, where the horizontal axis should be rate of flux change. She had a serious challenge in explaining the significance of the negative sign in Faraday's formula caused by her own lack of knowledge. Her CTS approach was a teacher-centred verbal approach with little participation and involvement of learners. The questions asked by the teacher during the lesson presentation promoted rote learning and chorus responses. During the lesson, she gave applause when one of her learners provided a good response. As part of her CTS, the teacher made no attempt to practically demonstrate Faraday's law. Furthermore, the teacher made no use of video simulations or videos to represent the concept of electromagnetic induction in line with Faraday's law. During the VSRI session when asked to justify her CTS approach, the teacher indicated that:

Like I once indicated to you earlier on that it was actually my first time to be teaching a grade 11 physical sciences class and later on the section of electromagnetic induction. After such a great exposure, I am hoping to develop better conceptual teaching strategies with time.

The teacher's ePCK for this component based on the big idea FL was therefore scored as '*limited*'. This is because a 'list of general strategies without indications of how they will be employed, are given' as stated in the rubric. Furthermore, 'there is no evidence of questions that will support conceptual understanding' as stated by the rubric.

4.5.7.4 REPRESENTATIONS

For the big idea of MF, the teacher used mathematical symbols on the chalkboard to represent the magnetic flux formula. Furthermore, the teacher used sketch graphs to represent the relationship between magnetic flux and magnetic field strength, magnetic flux and area of loop, magnetic flux and time for rotating loop. The chalkboard was used to present a numerical example of how to perform calculation using a flux formula.

However, no practical demonstration, videos, video simulations or PhET simulations were used to represent magnetic flux during the lesson.

The teacher's ePCK for this component based on the big idea MF was therefore scored as '*adequate*'. This is because 'the selection of representations (visual or symbolic) is insufficient and there is no evidence how the use of the representation will lead to increased understanding of concepts', as stated in the rubric.

For the second big idea of FL, the teacher used some graphs to represent relationships from Faraday's law, but there were mistakes in her graphs. Mathematical symbols were written on the chalkboard as a way of representing Faraday's formula, and the symbols were interpreted verbally. Furthermore, the teacher used the chalkboard to represent a numerical example of how to perform a calculation based on Faraday's law.

However, the teacher made no attempt to represent Faraday's law of electromagnetic induction using a practical demonstration. Furthermore, no videos, video simulations or PhET simulations were used to represent Faraday's law during the lesson. During the SSI session, while responding to a question based on challenges of representation, the teacher mentioned that:

It's very difficult for learners to understand the whole idea behind Faraday's law of electromagnetic induction without the assistance of some practical representation. Just mere verbal explanations and chalkboard notes are not enough.

The teacher's ePCK for this component based on the big idea FL was therefore scored as '*limited*'. This is because ' 'representations mentioned are vague and not specific to the key idea' as stated in the rubric. Furthermore, the 'representations are mentioned with no explanation of specific links to the concepts considered', as stated by the rubric.

4.5.8 COMPARISON OF TE4’s ENACTED PCK with her POST-INTERVENTION CoRes

Table 4.4.6 shows a summary comparing the post-intervention and enacted PCK scores per big ideas.

Table 4.4.6: Comparison of TE4’s post-intervention and enacted PCK scores

PCK Component	PCK SCORING LEVEL SUMMARY															
	POST								ENACTED							
	L		A		D		E		L		A		D		E	
	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL	MF	FL
Curricular saliency				o	x					o			x			
Learner understanding				o	x					o	x					
Conceptual teaching strategies				o	x					o	x					
Representations			x	o						o	x					

From table 4.4.6, the following observations were made regarding her post-CoRe scores compared to her enacted PCK scores:

The scores based on the big idea of FL all dropped by one level from being ‘*adequate’* for post-CoRes to being ‘l*imited*’ for enacted PCK. For the big idea of MF, score for Learner understanding and conceptual teaching strategies decreased by one level, from being ‘*developing*’ in the post-CoRes to being ‘*adequate*’ for the enacted PCK. The scores based on curricular saliency and representations for the big idea of FL remained unchanged as *developing* and *adequate* respectively.

The scores not highlighted at all is an indication that there was no noticeable change in enacted PCK scores compared to post-intervention scores. The scores highlighted in green shows a noticeable decrease in enacted scores compared to post-CoRe scores. The green highlighted scores provide evidence that the teacher’s personal PCK was not fully enacted during teaching.

In her post-intervention CoRes, the teacher mentioned that she shall conduct an experiment based on Faraday’s law and simulation videos to aid in explaining the flux concept. However, evidence based on the video playback suggested otherwise.

A practical demonstration and video simulation was suggested for use to teach Faraday's law. However, evidence from video playback shows that the teacher did not use any practical or simulation approach as part of her CTS while teaching the big idea of FL.

During the SSI session while responding to a question based on how often a teacher's planned lesson cannot translate or match reality during actual teaching, the teacher said that:

During the period of planning, its every teacher's wish to see the actual lesson proceeding in line with expectations. But the only weakness some of us have is to plan while overlooking the availability of the necessary teaching resources per specific topic…..

To make a comparison, the scores were represented on a numerical scale of 1 to 4, as was done in table 4.1.7. Table 4.4.7 shows the comparative PCK scores on a numerical scale.

Table 4.4.7: Summary of TE4's comparative PCK scores in the post-CoRes and in enactment on a scale ranging from 1 to 4.

PCK Components	**PCK Scoring levels**					
	Post-CoRe			**Enacted PCK**		
	MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
Curricular saliency	3	2	2.5	3	1	2.0
Learner understanding	3	2	2.5	2	1	1.5
Conceptual teaching strategies	3	2	2.5	2	1	1.5
Representations	2	2	2.0	2	1	1.5
Total (16)	11	8	9.5	9	4	6.5
Average (4)	2.8	2.0	2.4	2.3	1.0	1.7

From the numerical scores in table 4.4.7, there was a noticeable difference between post-CoRe scores and ePCK scores based on the big idea of MF, decreasing by an average of 0.5 points (from a score of 2.8 to 2.3). Furthermore, there was an even larger difference between post-CoRes scores and ePCK scores that was observed based on the second big idea of FL. The enacted PCK scores based on the big idea of FL decreased by an average of 1.0 points (from a score of 2.0 to 1.0) for PCK enactment. Combining the two big ideas, the overall average score decreased by an average of 0.7 points (from 2.4 for post-CoRe to 1.7) for ePCK, indicating that the teacher's personal PCK was ineffectively enacted during teaching.

4.6 COMPARISON OF THE TEACHERS' OVERALL ENACTED PCK WITH THEIR PRE- and POST- INTERVENTION CoRes.

This section presents a visual comparison of the teachers' average PCK scores for the pre-CoRes, post-CoRes and enactment. For the big idea of MF, the teachers' average PCK scores are presented in figure 4.5.

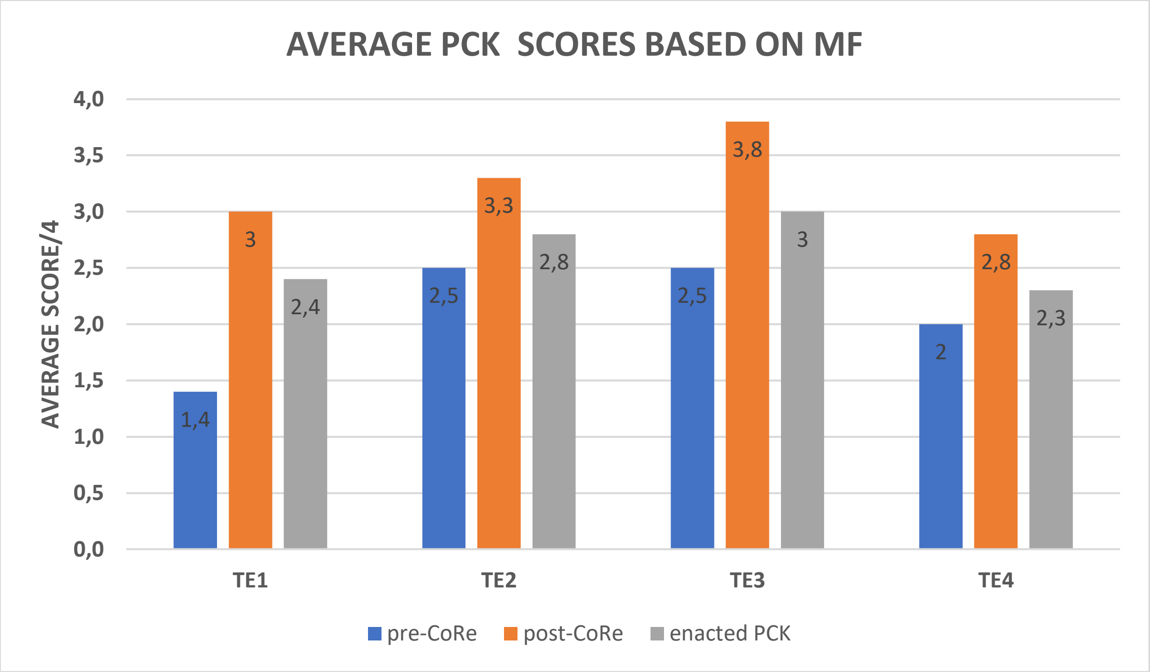


Figure 4.5: Average PCK scores for treatment group teachers based on MF. Source: Researcher's own.

One can immediately observe that the teachers' average post-CoRes score were noticeably higher than their pre-CoRes and enacted PCK scores. Furthermore, all the teachers' average pre-CoRes score was lower than their enacted PCK scores. Teacher TE3 had the highest average post-CoRes score of 3.8 and the highest average enacted PCK score of 3.0. Teacher TE1 had the lowest average pre-CoRes score of 1.4 while TE4 had the lowest average enacted PCK score of 2.3.

The teachers' average PCK scores based on the big idea of FL are presented in the form of a graph as shown in figure 4.6.

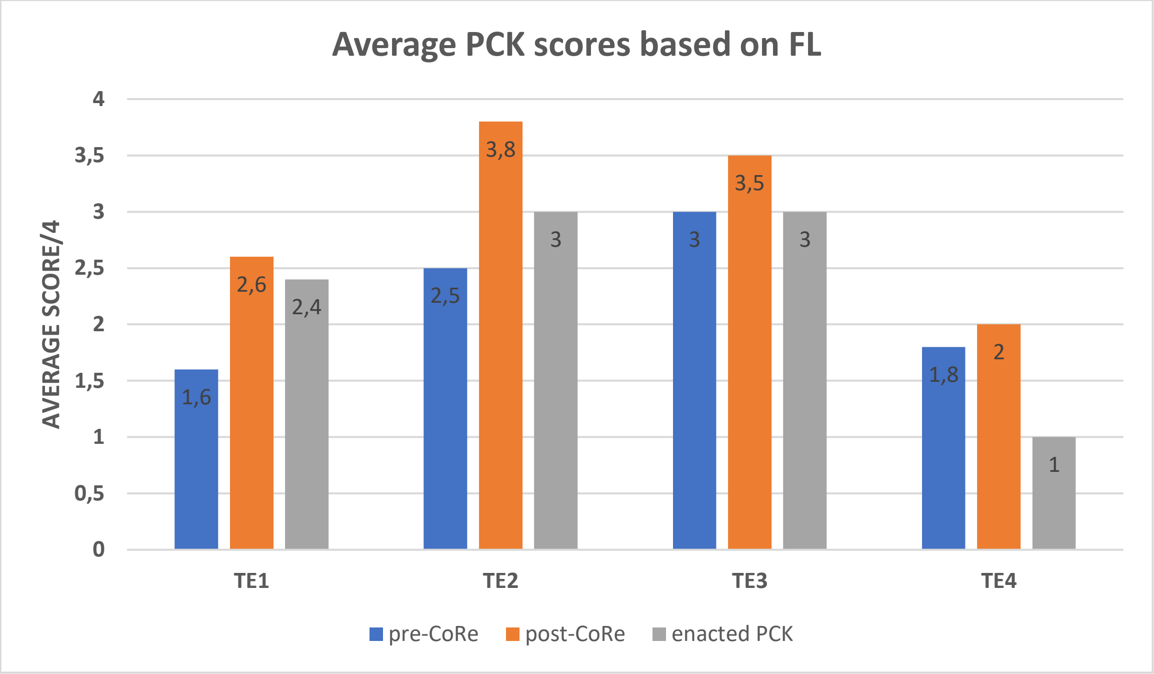


Figure 4.6: Average PCK scores for all treatment group teachers based on FL. Source: Researcher's own.

The immediate observation is that the teachers' average post-CoRes scores were noticeably higher than their pre-CoRes and enacted PCK scores. However, for all the teachers, the average enacted PCK scores were lower than their average post-CoRes scores. TE4 had the lowest average post-CoRes score of 2.0 while TE2 had the highest average post-CoRes score of 3.8. Furthermore, the TE1 and TE2's pre-CoRes scores were lower than their enacted PCK scores. Teachers TE2 and TE3 had the highest average enacted PCK score of 3.0. TE4's enacted PCK score was very low, even lower than her pre-CoRes score, amounting to a decrease of 0.8 points (from 1.8 to 1.0).

The teachers' overall average PCK scores were then presented in the form of a graph as shown in figure 4.7.

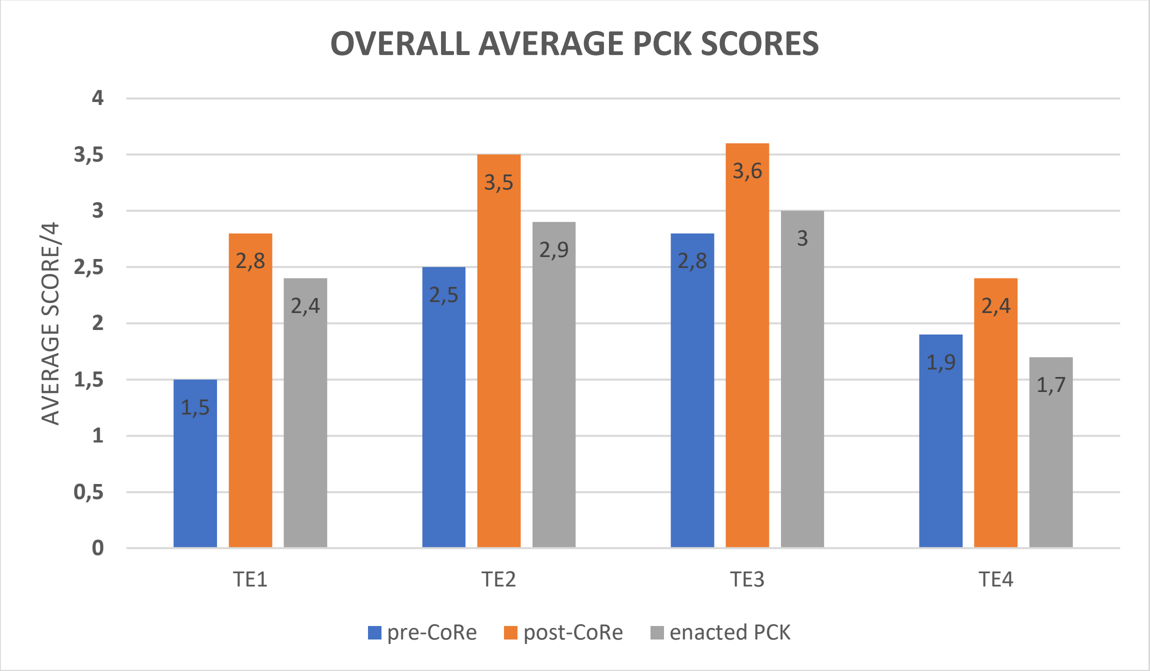


Figure 4.7: Overall average PCK scores for all treatment group teachers. Source: Researcher's own.

From figure 4.7, based on the overall averages for the big ideas of MF and FL, the immediate observation is that all the teachers' post-CoRes scores were higher than their pre-CoRes scores. However, the average enacted PCK scores were lower than their average post-CoRes scores. Furthermore, TE1, TE2 and TE3's average enacted PCK scores were higher than their pre-CoRes scores. Teachers TE2 and TE3 had the highest overall averages of enacted PCK scores of 2.9 and 3.0 respectively. TE4's overall enacted PCK scores compared to her post-CoRes scores decreased by an average of 0.2 (from 1.9 to 1.7).

From the numerical scores in table 4.5, there was a noticeable difference between the overall post-CoRes scores and the overall pre-CoRes scores based on the big idea of MF, increasing by an average of 1.2 points (from a pre-CoRes score of 2.1 to a post-CoRes score of 3.3). Furthermore, there was also a noticeable difference between the overall post-CoRes scores and the overall pre-CoRes scores that was observed based on the second big idea of FL. The overall scores increased by an average of 0.7 points (from a score of 2.3 to 3.0) for post-CoRes. Combining the two big ideas, the overall average score increased by an average of 1.0 points (from 2.2 for pre-CoRes to 3.2 for post-CoRes), indicating that the intervention had a positive impact on teachers' personal PCK.

Table 4.5: Summary of experimental group teachers' numerical PCK scores on a scale ranging from 1 to 4. comparing the pre and post-CoRes.

TEACHER	**PCK Components**	**Scores**					
		Pre-CoRe			**Post-CoRe**		
		MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
TE1	Curricular saliency	1	2	1.5	3	3	3.0
TE2		2	2	2.0	3	4	3.5
TE3		3	3	3.0	4	4	4.0
TE4		2	2	2.0	3	2	2.5
	Total score	8	9	2.2	13	13	3.3
	Average score	2.0	2.3		3.3	3.3	
TE1	Learner understanding	1	1	1	3	2	2.5
TE2		2	2	2.0	3	3	3.0
TE3		2	3	2.5	3	3	3.0
TE4		2	2	2.0	3	2	2.5
	Total score	7	8	1.9	12	10	2.7
	Average score	1.8	2.0		3.0	2.5	
TE1	CTS	1	2	1.5	3	3	3.0
TE2		3	3	3.0	4	4	4.0
TE3		3	3	3.0	4	3	3.5
TE4		2	2	2.0	3	2	2.5
	Total Score	9	10	2.4	14	12	3.3
	Average score	2.3	2.5		3.5	3.0	
TE1	Representations	2	2	2.0	3	3	3.0
TE2		3	3	3.0	3	4	3.5
TE3		2	3	2.5	4	4	4.0
TE4		2	1	1.5	2	2	2.0
	Total score	9	9	2.3	12	13	3.2
	Average Score/4	2.3	2.3		3.0	3.3	
OVERALL TOTAL SCORE		33	36		51	48	
OVERALL AVERAGE SCORE		2.1	2.3	2.2	3.3	3.0	3.2

From the numerical scores in table 4.6, there was a noticeable difference between the overall post-CoRes scores and the overall ePCK scores based on the big idea of MF, decreasing by an average of 0.7 points (from a score of 3.3 to 2.6). Furthermore, there was a noticeable difference between the overall post-CoRes scores and the overall ePCK scores that was observed based on second big idea of FL. The overall enacted PCK scores based on the big idea of FL decreased by an average of 0.7 points (from a score of 3.0 to 2.3) for PCK enactment. Combining the two big ideas, the overall average score decreased by an average of 0.7 points (from 3.2 for post-CoRes to 2.5) for ePCK, indicating that overall, the teachers' increased personal PCK was ineffectively enacted during teaching.

Table 4.6: Summary of experimental group teachers' numerical PCK scores on a scale ranging from 1 to 4, comparing enacted PCK to the post-CoRe scores.

TEACHER	**PCK Components**	**Scores**					
		Post-CoRe			**Enacted PCK**		
		MF (4)	**FL (4)**	**Average (4)**	**MF (4)**	**FL (4)**	**Average (4)**
TE1	Curricular saliency	3	3	3.0	2	2	2.0
TE2		3	4	3.5	3	3	3.0
TE3		4	4	4.0	3	3	3.0
TE4		3	2	2.5	3	1	2.0
	Total score	13	13	3.3	11	9	2.6
	Average score	3.3	3.3		2.8	2.3	
TE1	Learner understanding	3	2	2.5	2	2	2.0
TE2		3	3	3.0	3	3	3.0
TE3		3	3	3.0	3	3	3.0
TE4		3	2	2.5	2	1	1.5
	Total score	12	10	2.8	10	9	2.4
	Average score	3.0	2.5		2.5	2.3	
TE1	CTS	3	3	3.0	3	2	2.5
TE2		4	4	4.0	3	3	3.0
TE3		4	3	3.5	3	3	3.0
TE4		3	2	2.5	2	1	1.5
	Total Score	14	12	3.3	11	9	2.6
	Average score	3.5	3.0		2.8	2.3	
TE1	Representations	3	3	3.0	2	3	2.5
TE2		3	4	3.5	2	3	2.5
TE3		4	4	4.0	3	3	3.0
TE4		2	2	2.5	2	1	2.0
	Total score	12	13	3.3	9	9	2.4
	Average Sore/4	3.0	3.3		2.3	2.3	
OVERALL TOTAL SCORE		51	48		41	36	
OVERALL AVERAGE SCORE		3.3	3.0	3.2	2.6	2.3	2.5

4.7 SUMMARY OF CHAPTER 4

This chapter gave a detailed qualitative description of what transpired regarding all the experimental group teachers' PCK during this study based on the effect of a PCK intervention on teachers' PCK and learners' performance in electromagnetism. The four teachers' completed pre and post-intervention CoRes were scored and compared. The results generally show an increase in pPCK which can be ascribed to the intervention. Video-recorded lesson observations were conducted followed by VSRI and SSI sessions in order to capture each teacher's ePCK. Each teacher's ePCK was then scored and compared with their pPCK scores reflected in their post-CoRes. The overall impression indicated that their ePCK scores were at a lower level than that shown by their post-intervention PCK scores.

CHAPTER 5 QUANTITATIVE DATA ANALYSIS

5.1 INTRODUCTION

Creswell (2009) defines quantitative research as a strategy that puts more emphasis on quantifying data collection and analysis. This basically implies that quantitative research refers to amounting something. The quantitative research method provides efforts of investigating answers to the “how many, how much, to what extent” type of research questions (Bryman, 2012). In other words, the quantitative research method stresses heavily on measurement of variables in the physical and social world.

The quantitative data obtained from this study and the associated analyses are presented in this chapter. The analysis of the data is meant to respond to the third research question, which guided this study. The third research question:

> *What is the influence the teachers’ enacted PCK based intervention, on the performance of their learners?*

A baseline test based on a previously covered topic of mechanics was administered to the experimental and control groups before intervention. Their scores were initially analysed to determine the equivalence of the eight groups through hypothesis testing.

After the intervention period, a post-test based on electromagnetism was administered to the eight schools (four experimental and four control). The learners’ scores from the post-test were analysed quantitatively using the IBM® SPSS® Statistics 24 software.
To ascertain whether there was a statistically significant difference between the combined control group post-test data and the experimental group post-test data, an independent samples t-test was to be conducted. However, before administering the independent samples t-test, there was a need to check whether post-test data from the combined control and experimental groups were not in violation of assumptions underpinning t-test implementation. In other words, the researcher followed a statistically recommended procedure of conducting a t-test.

The quantitative data analysed in this chapter was based on the eight schools, four experimental and four control as shown in table 5.1.

Table 5.1: Summary of information of the eight sampled schools

School	Condition	Intervention	N	Group Total
E1	Experimental	PCK	49	200
E2	Experimental	PCK	51	
E3	Experimental	PCK	55	
E4	Experimental	PCK	45	
C1	Control	None	52	211
C2	Control	None	47	
C3	Control	None	62	
C4	Control	None	50	
TOTAL			411	411

This chapter presents a quantitative description and analysis of the data collected from the eight schools.

5.2 COMPARISON OF CONTROL GROUP AND EXPERIMENTAL GROUP BASELINE TEST

A baseline-test was conducted before the PCK intervention to establish whether or not the experimental and control groups were at the same level or comparable in terms of the topic of mechanics. To compare the control group with experimental group in terms of their performance in the baseline test, a statistical test was to be conducted. An independent samples t-test was considered to be more appropriate for comparing the baseline test for the combined group schools with the baseline test for the combined experimental group schools. The baseline test is given in Appendix H.

However, before the implementation of the independent samples t-test, six assumptions were set-up and the non-violation of each of the assumptions was checked. If all the assumptions were not violated, then the independent samples t-test was to be implemented. If at least one of the assumptions (excluding ***assumption 6***) was violated, then the independent samples t-test could not be implemented, and the remedy was to implement a non-parametric test. If only assumption 6 was violated, then the results of an independent samples t-test based on the assumption of unequal variances was to be considered.

5.2.1 CHECKING FOR THE VIOLATION OF ASSUMPTIONS

Before the implementation of the independent samples t-test between the combined control group and combined experimental group schools, the following six assumptions were checked against the baseline-test scores. However, the first three assumptions are similar as for the t-test, and similarly not violated.

Assumption 4: *There should be no significant outliers.*

Box and whisker plots for the control group baseline test and experimental group baseline test were generated as shown in figure 5.1.

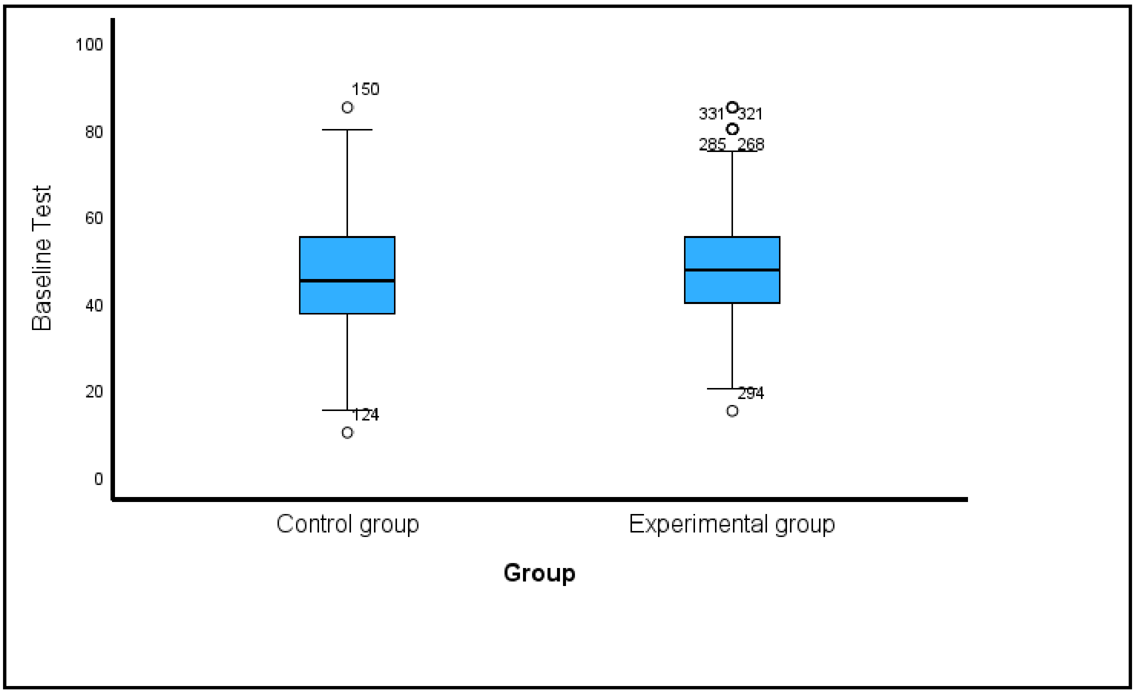


Figure 5.1: Box and whisker plots for baseline test (control group and experimental group). Source: Researcher’s own.

Since outliers are observed from the box and whisker plots in figure 5.1 for the control and experimental group’s baseline tests, therefore, assumption 4 was violated.

Assumption 5: *The dependent variable should be approximately normally distributed for each group of the independent variable.*

A Shapiro-Wilk test of normality for baseline test in the combined control group was first conducted to test the following hypotheses.

$H1_0$: *The baseline test for the control group is normally distributed.*

$H1_A$*: The baseline test for the control group is not normally distributed.

The Shapiro-Wilk test of normality results are shown in the table 5.2.

Table 5.2: Shapiro-Wilk test of normality for the baseline test in the combined control group (n=211).

Test of Normality (Shapiro-Wilk)		
Variable	**W**	**P**
Baseline test	0.981	0.007

The Shapiro-Wilk test of normality was conducted at a 5% level of significance to determine whether the baseline test data for the combined control group is normally distributed. The results in table 5.2 reveal that the null hypothesis ***($H1_0$)*** should be rejected for the combined control group baseline test (W=0.981, $p=0.007<0.05$) and conclude that the data was not normally distributed. Therefore assumption 5 was violated.

Second, a Shapiro-Wilk test of normality for a baseline test in the combined experimental group was conducted to test the following hypotheses.

$H2_0$*: *The baseline test for the experimental group is normally distributed.

$H2_A$: *The baseline test for the experimental group is not normally distributed.*

The Shapiro-Wilk test of normality results are shown in the table 5.3.

Table 5.3: Shapiro-Wilk test of normality for the baseline test in the combined experimental group (n=200)

Test of Normality (Shapiro-Wilk)		
Variable	**W**	**P**
Baseline test	0.955	0.001

The Shapiro-Wilk test of normality was conducted at a 5% level of significance to determine whether the baseline test data for the combined control group is normally distributed. The results in table 5.3 reveal that the null hypothesis ***($H2_0$)*** had to be for the combined experimental group baseline test (W=0.955, $p=0.001<0.05$) and conclude that the data was not normally distributed. Therefore assumption 5 was violated.

Assumption 6: *There needs to be homogeneity of variances (equality of variances).*

A Levene's test for equality of variances between the control group and the experimental group baseline tests was conducted to test the following hypotheses.

$H3_0$: *The variance of the control group baseline test is equal to the experimental group baseline test.*

***$H3_A$*: The variance of the control group baseline test is not equal to the variance experimental group baseline test.*

The Levene's test of equality of variances results are shown in the table 5.4**.**

Table 5.4: Levene's test of equality of variances of the baseline test for the control group and the experimental group.

Test of Equality of Variances			
Variable	**F**	**df**	**P**
Baseline test	0.125	1	0.724

A Levene's test of equality of variance was conducted at a 5% significance level to determine if the variance of the baseline test for the control group was equal to the variance of baseline test for the experimental group. The results shown in table 5.4 indicate that the null hypothesis (***$H3_0$***) should not be rejected for the baseline test (F (1) =0.125, p=0.724>0.05) and conclude that the variances were equal. Therefore assumption 6 was not violated.

Concluding Remarks after checking for violation of assumptions

Assumptions 4 and 5 were violated. Therefore, an independent samples t-test was considered statistically inappropriate to compare the baseline test for the control group with the baseline test for the experimental group. Instead, a non-parametric test, Mann-Whitney U test was implemented.

5.2.2 GUIDING ASSUMPTIONS FOR MANN-WHITNEY U TEST IMPLEMENTATION

The Mann-Whiney U test, just like any other test statistic comes associated with its own prerequisite assumptions, hence, before opting to administer the implementation of a Mann-Whitney U test, the baseline test data was checked to determine if there was non-violation of the following underlying assumptions.

Assumption 1: *The dependent variable should be measured on a continuous scale or ordinal scale.*

The baseline test data for both the control group schools, and the experimental group schools is on a continuous scale. Therefore, the first assumption was not violated.

Assumption 2: *Independent variable should consist of two categorical and independent groups.*

The second assumption was not violated since the combined control group and the combined experimental group are two independent groups.

Assumption 3: *The observations are independent in each group and no participant is in more than one group.*

Individual participants from each of the two combined groups wrote their own baseline test, and no participant was in more than one group. Hence, the third assumption was not violated.

Assumption 4: *A Mann-Whitney U test can be administered if at least one of the variables is not normally distributed. In addition, if the shapes of the two distributions are the same then the Mann Whitney U test is carried out to compare the medians of the dependent variable. However, if the two distributions have a different shape, the Mann-Whitney U test is implemented to compare the mean ranks.*

From the previous tests of normality conducted, the baseline test data of both the control group and the experimental group violated the assumption of normality (see results in Tables 5.2 and 5.3).

Two histograms were generated to determine if the shape of the baseline test data of the control group is identical to the shape of the baseline test data of the experimental group. The two histograms are shown in figures 5.2 and 5.3.

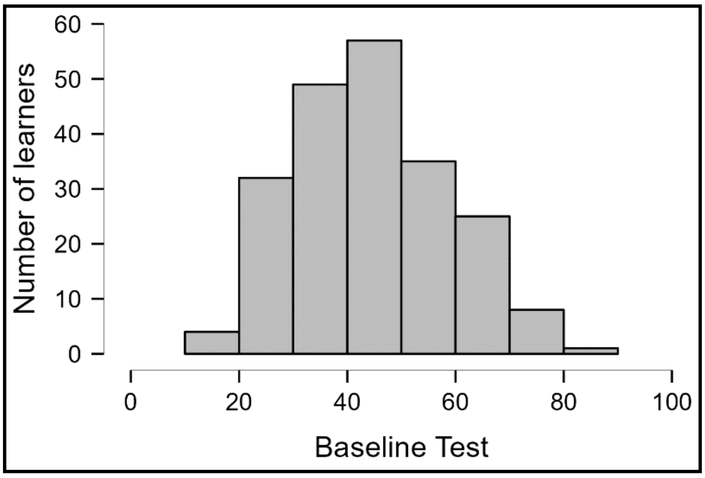


Figure 5.2: Histogram of baseline test data for the control group schools. Source: Researcher's own.

The histogram in figure 5.2 shows that the shape of the distribution of the post-test data of the combined control group schools is slightly positively skewed.

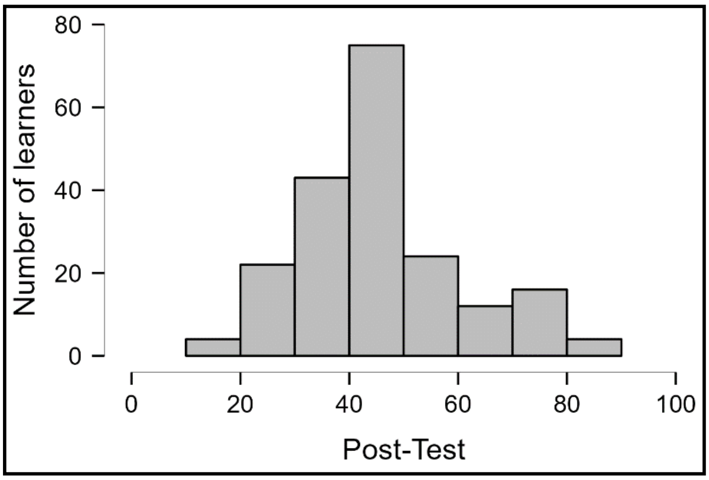


Figure 5.3: Histogram of baseline test data for the experimental group schools. Source: Researcher's own.

The histogram in figure 5.3 shows that the shape of the distribution of the baseline test data of the experimental group is approximately positively skewed, since the longer tail is on the right-hand side.

Concluding remarks

- Assumptions 1 to 3 were not violated. In addition, the baseline test data of both the control group and the experimental group violated the assumption on normality, hence, based on assumption 4, this suggests the implementation, of the Mann-Whitney U test.
- The shapes of the distributions of the baseline test data of the control group and the baseline test data of the experimental group are different. Therefore, the Mann-Whitney U test was implemented to compare the mean rank of the baseline test data of the control group and the mean rank of the baseline test data of the experimental group.

5.2.3 ADMINISTRATION OF THE MANN-WHITNEY U TEST

A Mann-Whitney U test was implemented non-parametrically, to compare the control group baseline test with the experimental group baseline test. The Mann-Whitney U test was conducted to test the following hypotheses:

> ***$H4_0$*** *There is no statistically significant difference between the median of the baseline test data of the control group and the median of the baseline test data of the experimental group.*
>
> ***$H4_A$****: There is a statistically significant difference between the median of the baseline test data of the control group and the median of the baseline test data of the experimental group.*

The results of the Mann-Whitney U test are shown in table 5.5.

Table 5.5: Comparison of control group baseline test with experimental group baseline test.

	Group	N	MEDIAN	Mann-Whitney U test	P
Baseline Test	**Control group**	211	45	20461,5	0,594
	Experimental group	200	47		
	Total	411			

A Mann-Whitney U test was conducted at a 5% level of significance to determine the significant difference between the control group baseline test and the experimental group baseline test. The results in table 5.5 reveal that there was no significant difference between the control group baseline test (Median=45) and the experimental group baseline test (Median=47) (U=20461.5, p=0.594>0.05). Therefore, the null hypothesis (***H4$_0$)*** was not rejected, hence performance in the baseline test was not different between the control group and the experimental group. Based on the statistical analysis, there was conclusive evidence indicating that the control group and the experimental group were at the same level in terms of learner performance before the intervention.

5.3 POST-TEST COMPARISON BETWEEN THE CONTROL AND EXPERIMENTAL GROUPS

To ascertain whether the PCK intervention had an impact on performance of learners whose teachers were subjected to PCK intervention, the post-test results of the control group were compared with the experimental group post-test results. The post-test is given in Appendix I.

An independent samples t-test was to be conducted to indicate if there were significant differences between the experimental group and the control group in their post-test performance. However, before the implementation of the independent samples t-test, the six assumptions for using the t- test were checked as was done for the baseline-test in section 5.2.

5.3.1 CHECKING FOR THE VIOLATION OF ASSUMPTIONS

However, the first three assumptions are similar as for the t-test, and similarly not violated.

Assumption 4: *There should be no significant outliers.*

Box and Whisker plots for the control group baseline test and experimental group baseline test were generated and are shown in figure 5.4.

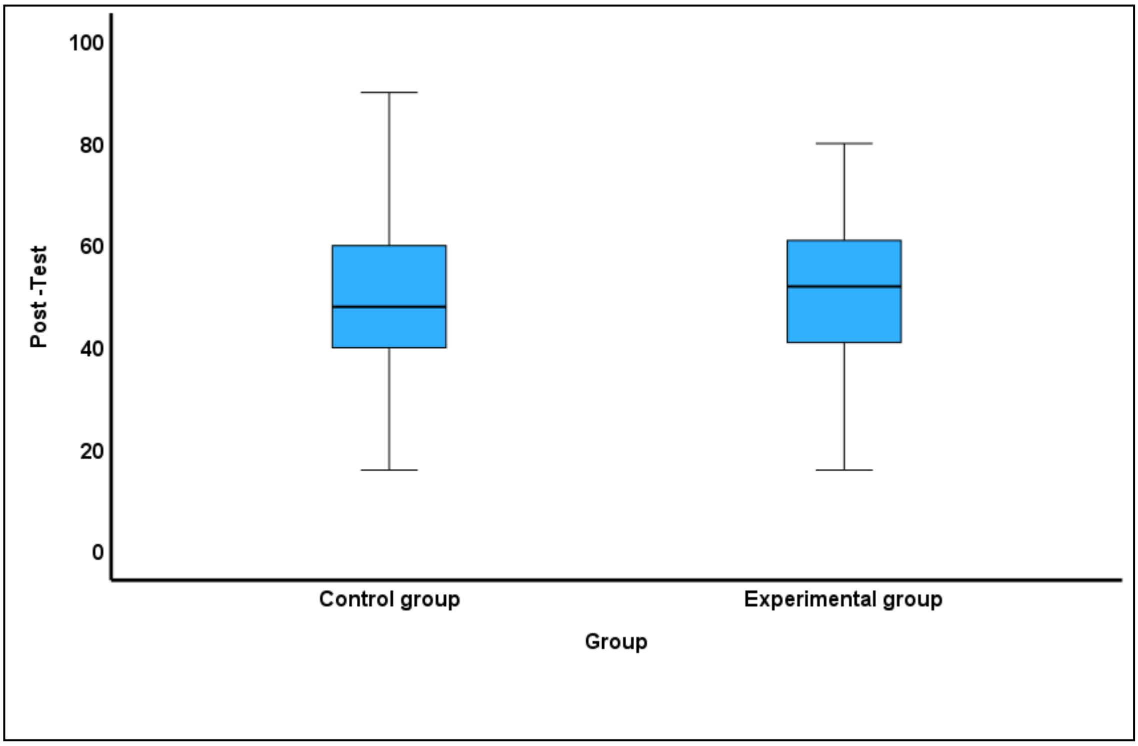


Figure 5.4: Box and whisker plots for post-test (control group and experimental group). Source: Researcher's own.

Both Box and Whisker plots in figure 5.4 show that there are no statistically significant outliers. Therefore, there was no violation of assumption 4.

Assumption 5: *The dependent variable should be approximately normally distributed for each group of the independent variable. Test for normality for post-test in the control group*

A Shapiro-Wilk test of normality was conducted based on the following hypotheses.

$H5_0$: *The post-test for the control group is normally distributed.*

$H5_A$: *The post-test for the control group is not normally distributed.*

The Shapiro-Wilk test of normality results of the test are shown in table 5.6.

Table 5.6: Shapiro-Wilk test of normality for the post-test in the control group (n=211)

Test of Normality (Shapiro-Wilk)		
Variable	**W**	**P**
Baseline test	0.991	0.205

The Shapiro-Wilk test of normality was conducted at a 5% level of significance to determine whether the post-test data for the control group was normally distributed. The results in table 5.6 reveal that we do not reject the null hypothesis (***$H5_0$***) for post-test (W=0.991, p=0.205>0.05), and conclude that the data is normally distributed. Therefore, assumption 5 was not violated for the control post-test data.

Test for normality for post-test in the experimental group

A Shapiro-Wilk test of normality was conducted to test the following hypotheses.

***$H6_0$:** The post-test for the experimental group is normally distributed.*

***$H6_A$**: The post-test for the experimental group is not normally distributed.*

The Shapiro-Wilk test of normality results of the test are shown in table 5.7.

Table 5.7: Shapiro-Wilk test of normality for the post-test in the experimental group (n=200)

Test of Normality (Shapiro-Wilk)		
Variable	**W**	**p**
Post-test	0,979	0,005

The Shapiro-Wilk test of normality was conducted at a 5% level of significance to determine whether the post-test data for the experimental group is normally distributed. The results in table 5.7 reveal that we reject the null hypothesis ***($H6_0$)*** for post-test (W=0.979, p=0.005<0.05) and conclude that the data is not normally distributed. Therefore, assumption 5 was violated for the experimental group post-test data.

Assumption 6: *There needs to be homogeneity of variances (equality of variances).*

A Levene's test for equality of variances was conducted to test the following hypotheses.

***$H7_0$**: The variance of control group post-test is equal to the experimental group baseline test.*

***$H7_A$:** The variance of control group post-test is not equal to the variance experimental group baseline test.*

The Levene’s test of equality of variances results are shown in table 5.8.

Table 5.8: Levene’s test of equality of variances of the post-test for the control group and experimental group

Test of Equality of Variances			
Variable	**F**	**df**	**P**
Post-test	3,534	1	0.061

A Levene’s test of equality of variance was conducted at 5% significance level to determine if the variance of the post-test for the control group is equal to the variance of post-test for the experimental group. The results in table 5.8 show that we do not reject the null hypothesis ***($H7_0$)*** for the post-test (F (1) =3.534, p=0.061>0.05) and conclude that the variances are equal. Therefore assumption 6 was not violated for the experimental group post-test data.

Concluding Remarks

Assumption 5 for experimental post-test data was violated. Therefore, an independent samples t-test is inappropriate to compare the post-test for the control group with the post-test for the experimental group. A non-parametric test, the Mann-Whitney U test was considered as an alternative test.

5.3.2 IMPLEMENTATION CRITERIA FOR MANN-WHITNEY U TEST

Before implementing the Mann-Whitney U test, the post-test data was checked to determine if the following assumptions were not violated:

The first three of the Mann-Whitney U test assumptions were like those given in section 5.2.2 and similarly not violated.

> **Assumption 4:** *A Mann-Whitney U test can be used when at least one of the variables is not normally distributed. In addition, if the shapes of the two distributions are the same then the Mann-Whitney U test is carried out to compare the medians of the dependent variable. However, if the two distributions have a different shape, the Mann-Whitney U test is used to compare mean ranks.*

From the previous test of normality conducted, the post-test data of the experimental group violated the assumption of normality (see also table 5.7).

Two histograms were then generated to determine if the shape of the post-test data of the control group school is identical to shape of the post-test data of the experimental group. The two histograms are shown in figures 5.5 and 5.6.

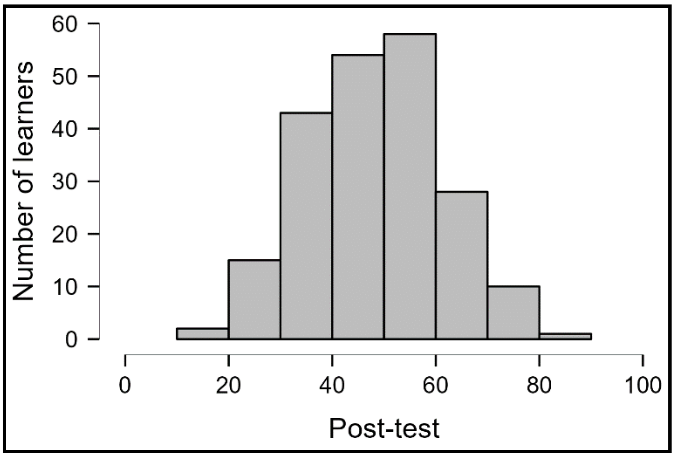


Figure 5.5: Histogram of post-test data for the control group schools. Source: Researcher’s own.

The histogram in figure 5.5 shows that the shape of the distribution of the post-test data of the combined control group schools is approximately normal.

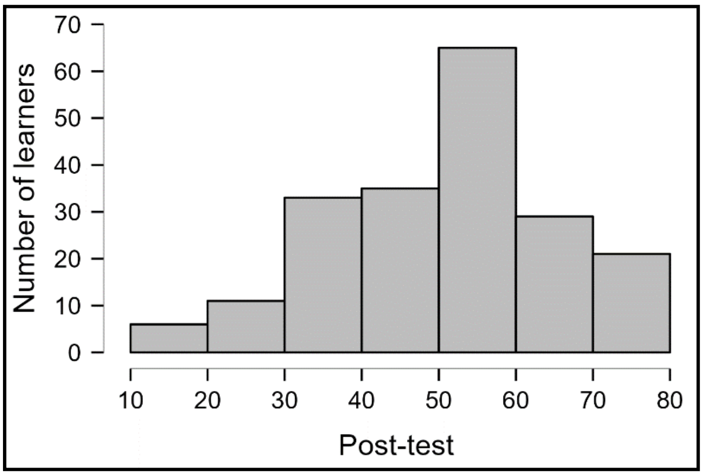


Figure 5.6: Histogram of post-test data for the experimental group schools. Source: Researcher's own.

The histogram in figure 5.6 shows that the shape of the distribution of the post-test data of the combined experimental group schools is approximately negatively skewed, since the longer tail is on the left-hand side.

Concluding remarks

- Assumptions 1 to 3 were not violated. In addition, the post-test data of the experimental group schools violated the assumption on normality, hence, based on assumption 4, this suggests the implementation of the Mann Whitney U test.
- The shapes of the distributions of the post-test data of the control group and the post-test data of the experimental group are different. Therefore, the Mann-Whitney U test was implemented to compare the mean rank of the post-test data of the control group and the mean rank of the post-test data of the experimental group.

5.3.3 ADMINISTRATION OF THE MANN-WHITNEY U TEST

A Mann-Whitney U test was implemented to compare the post-test data of the control group and the post-test data of the experimental group.

To effectively implement the Mann-Whitney U test, the following hypotheses were formulated:

> ***$H8_0$:*** *There is no statistically significant difference between the mean rank of the post-test data of the control group and the mean rank post test data of the experimental group.*
>
> ***$H8_A$****: There is a statistically significant difference between the mean rank of the post-test data of the control group and the post test data of the experimental group.*

The Mann-Whitney U test results are shown in table 5.9.

Table 5.9: Comparison of control group post-test with experimental group post-test.

Variable	Group	N	Mean Rank (MR)	Mann-Whitney U	P
Post Test	**Control group**	211	185,05	18789,000	0,043
	Experimental group	200	217,56		
	Total	411			

A Mann-Whitney U test was conducted at a 5% level of significance to determine the significant difference between the control group post-test and the experimental group post-test. The results in table 5.9 reveal that there is a significant difference in performance between the control group post-test (MR=185,05) and the experimental group post-test (MR=217.56) (U=18789.0, p=0.043<0.05). Therefore, the null hypothesis (***$H8_0$****) is* rejected, and alternative hypothesis **($H8_A$)** was accepted, hence, there was a statistically significant difference in post-test performance between the control group and the experimental group. More specifically, the performance of learners from the experimental group was better than that of learners from the control group.

5.4 SUMMARY OF CHAPTER 5

Results of control group baseline test were compared with the experimental group baseline test to see if they were at the same level before the intervention. Assumptions 4 and 5 were violated. Therefore, an independent samples t-test was considered statistically inappropriate to compare the baseline test data for the control group with the baseline test data for the experimental group. Instead, a non-parametric test, the Mann-Whitney U test was implemented. The results from the Mann-Whitney U test confirmed that there was no statistically significant difference between the control group baseline test data and the experimental group baseline test data. In other words, the control group was at the same level with the experimental group prior to intervention.

Data collected from the control group post-test was compared with the experimental group post-test to determine if there was a statistically significant difference in their performance after the PCK intervention. However, two out of the six assumptions governing the administration of a t-test were violated by post-test data from the control group and experimental group. More specifically, assumptions 4 and 5 were violated. Therefore, an independent samples t-test was considered statistically inappropriate to compare the post-test data for the control group with the post-test data for the experimental group. Instead, a non-parametric test, the Mann-Whitney U test was implemented based on its assumptions. The results from the Mann-Whitney U test confirmed that there was a statistically significant difference between the control group post-test data and the experimental group post-test data. In other words, the experimental group performed better after PCK intervention than the control group.

CHAPTER SIX: DISCUSSION AND CONCLUSION

6.1 INTRODUCTION

In this chapter, the researcher presents the findings and answers the research question. First, conclusions from qualitative data extracted from the treatment group teacher participants will be presented, followed by conclusions from quantitative data based on Grade 11 learners' post-test performance. Then, the researcher shall integrate, compare, and synthesise the qualitative and quantitative research findings while being guided by the mixed methods research approach. The implications of the research findings, limitations, and recommendations for further studies shall be presented in this chapter. Finally, an ultimate conclusion shall be given, marking the end of the study.

This principal research question which guided this study was:

What is the effect of a generic PCK-based intervention on in-service teachers' PCK and their learners' performance in EMI, and how can it be understood?

In order to respond to the main research question, the following sub-questions were formulated:

I. *What is the influence of the intervention on the teachers' personal PCK?*

II. To what extent is the teachers' personal PCK manifested in the enacted PCK?

III. What is the influence of the teachers' enacted PCK on the performance of their learners?

This study was approached from the mixed methods perspective which involved collecting and analysing data using multiple data collection instruments. The researcher used the following instruments for collecting qualitative data from in-service teacher participants: *Pre-CoRe, Post-CoRe, video-recorded lesson observations, VSRI sessions and SSI sessions.*

The researcher used the baseline test to collect and analyse quantitative data from learner participants prior to intervention. The baseline test was based on Grade 11 Mechanics, a topic which had already been covered during the first term in accordance with the ATP. The quantitative baseline test scores were statistically analysed to ascertain whether the two groups were at the same level of academic ability prior to intervention. The researcher used the post-test to collect and analyse quantitative data from learner participants after the teachers who underwent the intervention as well as the control group teachers who taught the topic EMI. The post-test was based on Grade 11 EMI, a topic which was covered during the second term in accordance with the ATP, and which was selected for studying the teachers' PCK following the intervention. The quantitative post-test scores were statistically analysed to ascertain whether the PCK intervention on teachers' PCK had an impact on their learners' performance in EMI. The following sections give detailed discussions based on findings from this mixed methods study.

6.2 DISCUSSION OF QUALITATIVE FINDINGS

The qualitative aspect of this mixed methods study involved gathering data from teachers in the treatment group through the use of multiple data collection instruments. Data was initially captured through the use of the pre-CoRe. This was conducted prior to intervention. During the post-intervention period, the teachers were requested to construct their CoRes using the guiding tabular template which was given to them. This was followed by video-recorded lesson observations in order to explore the teachers' ePCK during their teaching of EMI. VSRI and SSI sessions were then held for teachers to reflect on their lessons as well as share their own views pertaining to the study. Their pre-CoRes, post-CoRes and enacted PCK were then scored using a rubric.

6.2.1 RESPONDING TO THE FIRST RESEARCH SUB-QUESTION

The general observed trend in table 4.6 indicates that there was an upward shift in scores in almost all the PCK components (from pre-CoRe scores to post-CoRe scores) and for all the four treatment group teachers. There was a noticeable difference between pre-CoRe scores and post-CoRe scores based on the big idea of MF. The overall picture observed from figure 4.5 based on the first big idea of MF suggests that the average post-CoRe scores were higher than the average pre-CoRe scores. This is further supported by results based on the big idea of MF in table 4.5 showing an increase by an overall average of 1.2 points, from pre-CoRe (score = 2.1) to post-CoRe (score = 3.3). Similarly, the trend observed in figure 4.6 and table 4.5 shows a noticeable difference between the pre-CoRe and post-CoRe scores, based on the second big idea of FL. The observation based on the big idea of FL shows an increase by an overall average of 0.7 points, from pre-CoRe (score = 2.3) to post-CoRe (score = 3.0). The trend observed in table 4.5 indicates that there was an overall score increase by an average of 1.0 point from pre-CoRe (overall score = 2.2) to post-CoRe (overall score = 3.2). This gives the general impression that the teachers had a better understanding of PCK when completing their post-CoRes compared to pre-CoRes. Based on the findings of this research study, the overall deductive picture is that the intervention had a positive impact on teachers' pPCK development.

The trend amongst the teachers as reflected in table 4.5 shows a noticeable difference between the pre-CoRe scores and post-CoRe scores based on *knowledge of curricular saliency*. The overall PCK score for the big idea of MF based on *curricular saliency* increased by an overall average of 1.3 points (from 2.0 for pre-CoRe to 3.3 for post-CoRe).

Similarly, the overall PCK score for the big idea of FL based on *curricular saliency* increased by an overall average of 1.0 point (from 2.3 for pre-CoRe to 3.3 for post-CoRe). This means that, there was a demonstration by the four teachers to have developed an improved *knowledge of curricular saliency*. This was indicated by their ability to pay attention to appropriate sequencing of the ideas in their post CoRes compared to their pre-CoRes. Furthermore, the teachers were able to identify in their post-CoRes, some pre-concepts including those needed in discussing the introductory definitions. In this regard, all teachers explicitly mentioned the magnetic effect of coil carrying current for the first big idea of MF, and magnetic flux for the second big idea of FL as pre-concepts in their post CoRes than in their pre-CoRes. They identified and stated the subordinate ideas that account for the better application of equations and definitions based on both MF and FL in their post-CoRes than in their pre-CoRes. Additionally, all teachers explicitly mentioned in their post-CoRes, the issue of the angle in the flux formula, the negative sign in Faraday's formula, and application of RHR as their anticipated difficulties to be encountered when teaching MF and FL. In contrast, while completing their pre-CoRes, their responses were vague and inappropriately sequenced.

The trend in table 4.5 shows a noticeable increase for the teachers from the pre-CoRe scores and post-CoRe scores based on *Learner understanding* (which included *learners' prior knowledge* and *what is difficult or easy to teach)*. The overall PCK score for the big idea of MF based on *Learner understanding* increased by an overall average of 1.2 points (from 1.8 for pre-CoRe to 3.0 for post-CoRe). Similarly, the overall PCK score for the big idea of FL based on *Learner understanding* increased by an overall average of 0.5 points (from 2.0 for pre-CoRe to 2.5 for post-CoRe). Regarding the PCK component of *Learner understanding* all four treatment group teachers were able to cite at least some appropriate difficulties associated with teaching the big ideas of MF and FL. The magnetic effect of coil-carrying current and magnetic field strength were mentioned by the four teachers as part of the learner's prior knowledge for the big idea of MF. Although their individual post-CoRe scores based on the PCK component of l*earner understanding* were lower than their corresponding scores in the other three PCK components, they were higher than their pre-CoRe scores for the same PCK component indicating that the intervention had a positive impact for this component.

The trend in table 4.5 shows that there was an improvement in teachers' responses to the post-CoRes compared to the pre-CoRe responses regarding the PCK component of CTS. The observation based on PCK component of CTS for the first big idea of MF showed an increase by an overall average of 1.2 points (from 2.3 for pre-CoRe to 3.5 for post-CoRe). Similarly, the overall score for the big idea of FL based on *CTS* increased by an overall average of 0.5 points (from 2.5 for pre-CoRe to 3.0 for post-CoRe). The teachers were able to suggest better CTSs compared to their pre-CoRe responses for the same PCK component of CTS. Conceptual teaching strategies suggested by three of the four teachers (TE1, TE2, and TE3) in the post-CoRe were highly learner-centred and there is evidence that the strategies would support a conceptual understanding of MF and FL compared to their corresponding pre-CoRe response. In their post-CoRes, all four teachers suggested better guiding questions related to definitions, distinctions and relationships between concepts, and numerical calculations compared to their pre-CoRe responses.

The trend in table 4.5 shows an improvement in teachers' responses to their post-CoRes compared to their pre-CoRe responses regarding *representations*. The first big idea of MF showed an increase by an overall average of 0.7 points (from 2.3 for pre-CoRe to 3.0 for post-CoRe). Similarly, the overall score for the big idea of FL based on *representations* increased by an overall average of 1.0 point (from 2.3 for pre-CoRe to 3.3 for post-CoRe). In their post-CoRes, the four teachers generally presented an adequate selection of better *representations* (visual and symbolic or graphical or pictorial compared to pre-CoRe responses), sufficient to support conceptual development of specific aspect(s) of MF and FL. Furthermore, three of the four teachers (TE1, TE2 and TE3) suggested the use of macroscopic, visual and symbolic *representations* like simulations and videos in addition to explanatory notes to enforce aspect(s) of MF and FL concepts in their post-CoRes. Some teachers remarked that they do not have apparatus for practical work.

Responding to the first research sub-question which was formulated as follows:

What is the influence of the intervention on the teachers' personal PCK?

The general overview from both figure 4.5 and table 4.5 indicates that the intervention had an impact on in-service teachers' personal PCK. The answer to this question is guided by the comparison of the pre-CoRe scores and post-CoRe scores in which case the post-CoRe scores were better. Despite the isolated challenges experienced by teachers during completion of their post-CoRes, the influence of intervention on teachers pPCK cannot be disregarded.

6.2.2 RESPONDING TO THE SECOND RESEARCH SUB-QUESTION

A quick observation of figure 4.7 reveals that the overall enacted PCK scores were prevalently lower than those for the post-CoRes for nearly all the teachers. The general observed trend in table 4.6 indicates that there was a downward shift in scores in almost all the PCK components (from post-CoRe scores to ePCK) and for all four teachers.

There was a noticeable difference between post-CoRe scores and ePCK scores based on the big idea of MF. The overall picture observed from figure 4.5 based on the big idea of MF indicate that the average post-CoRe scores were higher than the average ePCK scores. Table 4.5 shows a decrease by an average of 0.7 points, from post-CoRe (score =3.3) to ePCK (score =2.6). Similarly, the trend observed in figure 4.6 shows a noticeable difference between the post-CoRe and ePCK scores based on the second big idea of FL. Table 4.6 for the big idea of FL shows a decrease by an average of 0.8 points, from post-CoRe (score =3.0) to ePCK (score =2.3). Table 4.6 indicates that there was an overall score decrease by an average of 0.7 points. from post-CoRe (overall score =3.2) to ePCK (overall score = 2.5). This gives the general impression that the sampled teachers had some challenges of effectively enacting their PCK especially for the second big idea of FL.

Although individual teachers might have faced challenges during PCK enactment, footprints of the effectiveness of the intervention were evident for some specific PCK components. All the sampled teachers introduced their lessons reflecting on their previous lesson based on the magnetic field around a coil carrying current. In other words, there was recognition of *learners' prior knowledge* which was consistent with their post-CoRes.

Three of the four teachers (TE1, TE2 and TE3) made use of video and PhET simulations as an effective CTS approach during their PCK enactment. This CTS approach was in line with what they had suggested in their post-CoRes. An effort to stage a learner-centred lesson was observed especially during video simulations by TE1, TE2, and TE3. Furthermore, the teachers all made effective use of chalkboard, textbooks and worksheets to assist learners' conceptual understanding of MF and FL. All teachers ensured that they gave their learners worked numerical examples as part of their CTS before providing their learners with formative and summative assessments as suggested in their post-CoRes. The *representations* used for CTS by TE1, TE2, and TE3 were consistent with what they had mentioned in their post-CoRes. In their post-CoRes, teachers mentioned their use of video simulations to assist in explaining magnetic flux and Faraday's law. Furthermore, three of the four teachers' (TE1, TE2, and TE3) use of video simulations during teaching were consistent with their post-CoRes and assisted in addressing some *learner misconceptions* as well as *what is difficult to teach* with regard to the angle when dealing with flux and the negative sign in Faraday's formula.

In response to the second research sub-question which was formulated as follows:

To what extent is the teachers' personal PCK manifested in the enacted PCK?

The general observation from the summarised information presented in table 4.6, gives the impression that there was a downward shift from post-CoRe scores to ePCK scores in all the PCK components and for all four of treatment group teachers. The enacted PCK scores were prevalently lower than those for the post-CoRes. In other words, teachers had some challenges of effectively enacting their PCK. The challenges they faced might have had a negative impact on teachers' PCK development. Therefore, based on the research findings from this study, the extent to which the teachers' personal PCK manifests itself as enacted PCK in specific components and for specific concepts was somehow compromised.

6.3 DISCUSSION OF QUANTITATIVE FINDINGS

The quantitative data obtained from this study and the associated analyses are presented in this section. The groups' baseline and post-test scores were analysed quantitatively using IBM® SPSS® Statistics 24 software. The analysis of the data is meant to respond to the third research sub-question, which guided this study. The third research sub-question:

> *What is the influence of the teachers' enacted PCK based on the performance of their learners?*

A baseline test based on a previously covered topic of Mechanics was administered to all learners from the eight participating schools. Schools were then allocated to two groups by matching schools of similar average performance. Their baseline test scores were analysed statistically prior to the intervention to determine the equivalence of the two groups through hypothesis testing. A Mann-Whitney U test was implemented non-parametrically, to compare the control group baseline test scores with the experimental group baseline test scores. The Mann-Whitney U test was conducted to test the following hypotheses:

> ***$H1_0$*** *There is no statistically significant difference between the median of the baseline test data of the control group and the median of the baseline test data of the experimental group.*
>
> ***$H1_A$****: There is a statistically significant difference between the median of the baseline test data of the control group and the median of the baseline test data of the experimental group.*

The results from the Mann-Whitney U test revealed that there was no significant difference between the control group baseline test scores and the experimental group baseline test scores. Therefore, the null hypothesis was accepted, hence performance in the baseline test was not different between the control group and the experimental group. Based on the statistical analysis, there was conclusive evidence indicating that the control group and the experimental group were at the same level in terms of learner performance before the intervention.

After the intervention, all learners from both groups participated in a post-test based on the Grade 11 topic of EMI. The quantitative data extracted from the post-test was then analysed statically through hypotheses testing. A Mann-Whitney U test was conducted at a 5% level of significance to determine if there was a statistically significant difference between post-test scores from the control group and the experimental group. To effectively implement the Mann-Whitney U test, the following hypotheses were formulated:

> ***$H2_0$:** There is no statistically significant difference between the mean rank of the post-test data of the control group and the mean rank of the post test data of the experimental group.*
>
> ***$H2_A$**: There is a statistically significant difference between the mean rank of the post-test data of the control group and the post test data of the experimental group.*

The results from the Mann-Whitney U test revealed that there was a significant difference in performance between the control group post-test and the experimental group post-test. Therefore, the null hypothesis was rejected, and the alternative hypothesis was accepted. More specifically, the performance of the learners from the experimental group was better than that of learners from the control group. This implies that the better performance of learners from the treatment group can be attributed to the enhanced enacted PCK of their teachers.

6.4 ANSWERING THE MAIN RESEACH QUESTION

To answer the main question, there is a need for integrating answers from the three sub-questions to identify the common ground where the data sets seem to be converging.

The findings from this study guided by pre- and post-CoRe scores revealed that the intervention had a positive impact on teachers' personal PCK (see table 4.5; figure 4.5 and section 6.2.1). However, the teachers' enhanced pPCK, as depicted by their post-CoRes, were not effectively translated into ePCK. All teachers experienced a downward trend in their ePCK scores compared to their post-CoRe scores, as shown in figure 4.7. Nevertheless, three of the four teachers (TE1, TE2, and TE3) had higher overall average ePCK scores than their pre-CoRe scores. The noticeable improvement from pre-CoRe to ePCK can only be attributed to and explained in terms of the footprints of PCK intervention. Based on these qualitative findings, it can be concluded that the PCK intervention had a positive impact on teachers' PCK. All the teachers had a specific challenge related to the big idea of FL, the most common challenge being that of explaining the physical significance of the negative sign in Faraday's law formula. All except T3 did not apply Lenz's law in determining the direction of the induced field. Instead, they simply referred to the application of the right-hand rule to determine the direction of the induced current.

Regarding the quantitative results, the Mann-Whitney U test conducted under hypothesis revealed a statistically significant difference in performance between the control group post-test and the experimental group post-test. Combining the qualitative and quantitative results implies that the better performance of learners from the treatment group can be attributed to the enhanced enacted PCK of their teachers.

In response to the second research sub-question which was formulated as follows:

> *What is the effect of a generic PCK-based intervention on in-service teachers' PCK and their learners' performance in EMI, and how can it be understood?*

Based on the findings of the study, it is concluded that the teachers' PCK as well as learners' performance in EMI were enhanced by the generic PCK intervention. This can be understood in terms of the knowledge flow from cPCK to pPCK and the associated skills learnt during the PCK intervention in this study had a positive impact of enriching teachers' pPCK (see figure 4.7 and table 4.5). This was consistent with the conceptual framework used in this study (see figure 2.2). The enhanced pPCK was translated into action as ePCK during teaching. Although the extent to which the enhanced pPCK was less pronounced, results from the Mann-Whitney U test can only be attributed to and explained in terms of the teachers' ePCK. In other words, the teachers' enhanced PCK manifesting during teaching had a positive influence on learner performance.

There was enhancement in PCK seen in the post-CoRes and learner performance, but that the challenges to enact the PCK was a limiting factor. It seems that content knowledge is one challenge. It also seems that using a generic intervention highlights the challenge of poor content knowledge. There was some transfer of PCK skills but no opportunity for enhancement of content knowledge.

6.5 IMPLICATIONS AND CONTRIBUTIONS

The researcher found that a generic PCK intervention was transferred to a specific topic, enhancing teachers' PCK and influenced learner outcomes. In this topic, this is a major contribution to the PCK research field.

Although in-service teachers from the treatment group had some challenges regarding specific components while completing their post-CoRes, most of their responses indicated an improvement in their personal PCK. While constructing the CoRes after the intervention seemed to be easier for nearly all the in-service teachers, it is the enactment and integration of PCK components which presented nearly all of them with specific challenges.

The study exposes various content-related challenges based on EMI to Grade 11 Physics teachers in South Africa. Hence, it is apparent that continued professional development should involve content knowledge of EMI. The content-related challenge at the forefront was that of failure to realise the interrelatedness between Faraday's law and Lenz's law. This was demonstrated in difficulties to explain the negative sign when dealing with Faraday's law, and to determine the direction of induced current by applying the RHR to the induced field. This greatly affected the development of enacted PCK. Some teachers had a challenge of providing a convincing explanation regarding the physical significance of the angle when dealing with the flux formula. These implications from the research findings indicate the need to provide more detail in the CAPS syllabus or to workshop especially novice teachers about the CAPS syllabus in terms of specific expectations per subordinate idea.

6.6 DISCUSSION

Generally, the PCK in EMI depicted by teachers in their post-CoRes was rated as developing. On the other hand, the PCK demonstrated by teachers during enactment was generally perceived to be of lower quality if compared to the PCK reported in their post-CoRes. This implies that even though teachers might have accomplished higher PCK traits after the intervention, their instructional strategies could not adequately promote effective learning. The findings concur with Buma and Sibanda (2022) who observed the complexity of contextual capture of enacted PCK.

The findings from this study revealed that the teachers' PCK enactment was not related to teaching experience in this sample. This concurs with literature (Mapulanga et al., 2022; Suprayogi et al., 2017). The results of this study are in agreement with Busaka et al. (2022) and Park et al. (2020) who realised the absence of a relationship between the skills during PCK enactment and teacher's experience.

Content-related challenges were more pronounced for FL than for MF. Specifically, the teachers were inadequately prepared to address learning difficulties associated with the negative sign, RHR and Lenz's law. These challenges show how the lack of content knowledge in a specific concept nullifies teachers' ePCK. The same observation was made by Coetzee et al. (2020) who indicated the variation of teachers' PCK from one concept to the next.

The findings from this study showed that the component learner understanding (which is a result of merging the component learners' prior knowledge and what makes the subject easy or difficult to teach) was the most poorly enacted PCK component. This concurs with Mthetwa-Khunene et al. (2015), who observed that teachers' pedagogical decisions were ineffective due to their inadequate understanding of learners' prior knowledge. The findings from this study are consistent with Mapulanga et al. (2022) who noted that 'what is difficult to teach' was the worst-enacted component. It is therefore quite imperative for teachers to develop more knowledge about leaners' difficulties for them to enable learners to understand difficult concepts. Mazibe et al. (2018) advocate for the necessity of teachers to have knowledge of learners' challenges. TE3 was the only participant who showed awareness of learners' challenges when he mentioned that the tricky part during calculations using the flux formula involved the angle.

According to Mavhunga (2018), teachers tend to ignore the importance of running some tests with their apparatus prior to demonstrating them in class. This was typical of teacher TE3 who tried to demonstrate the electromagnetic induction phenomenon to his learners. However, the demonstration was unsuccessful because he moved a magnet too far from the coil and tried to measure induced current with an ammeter instead of a galvanometer, indicating a lack of knowledge of representations as well as lack of knowledge of laboratory equipment.

According to Kind (2009), a teacher who finds it difficult to explain concepts to the learners exhibits PCK of poor quality. Furthermore, Mavhunga (2018) remarked that teachers with poorly developed PCK tend to possess some misconceptions which unfortunately will end up being transferred to learners during PCK enactment. This describes TE4 where so much went wrong especially during her teaching of FL. She did not know more than what is given in the CAPS document and, she did not comprehend the direction of induced current. TE4's' lack of knowledge was demonstrated when she acknowledged one of her learners' explanation related to Lenz's law. Additionally, TE1 did not explain the significance of the rate of change of flux in electromagnetic induction. While teaching the big idea of MF, TE4 should have talked about the rate of flux change, not just flux change. Consequently, she ended up presenting an incorrect graph where the horizontal axis should be $\Delta\varphi/\Delta t$ and not $\Delta\varphi$ as shown in figure 4.4.24. Poor content knowledge and misconceptions thus compromised T4's PCK and puts her knowledge of curricular saliency and learner understanding in the spotlight.

PCK of treatment group teachers in this study played a crucial role in supporting the refined consensus model in education. The findings of this study reveal a positive outcome on teachers personal PCK transferred from collective PCK during intervention. This is evidenced by their higher post-CoRe scores compared to their pre-CoRe scores. The overall enactment of PCK was fairly done. However, all the treatment group teachers` had some isolated challenges based on their enactment of specific PCK component. The better performance by treatment group learners in the post-test compared to the control group learners is evidence that enhanced PCK was transferred to treatment group learners.

6.7 LIMITATIONS

The investigation was based on only eight schools, four of which were used as the experimental group. The sample size does not justify generalisability of research findings. This limitation is inherent to all qualitative studies.

Furthermore, this study did not involve elements of action or longitudinal research to enable effective follow-up on methods. It is possible that teachers gain short-lived PCK, meaning that the benefit of the intervention may diminish as time passes. PCK intervention on in-service teachers' PCK could only be conducted during the second term of 2021 in line with the revised national ATP, hence the influence of the intervention on aspects of teachers' PCK about Grade 11 EMI may have decreased by the time of lesson delivery.

Despite these limitations the study yielded some valuable results, suggesting that generic PCK interventions may be beneficial to teachers and learners.

6.8 RECOMMENDATIONS

Based on the findings from this study, the researcher strongly recommends that teachers' content knowledge should be addressed, together with PCK. The result of this study shows that a generic PCK intervention did result in transfer to a specific topic. However, further studies are needed to investigate which interventions would be better: Generic PCK combined with specific content knowledge or topic-specific PCK?

The study showed that personal PCK gained from the intervention was not fully enacted. Further studies should therefore be conducted related to bridging the gap between teachers' personal PCK and enacted PCK.

Interventions should be conducted to investigate teachers' PCK related to their understanding of the challenges in 'learners' prior knowledge and what is difficult to teach. The 'teachers' content knowledge related to their understanding of the interrelatedness between Faraday's law, RHR and Lenz's law needs to be explored for Grade 11 teachers. The physical significance of the angle as well as the need to represent flux diagrams in 3D format requires further investigation in order to improve in-service teachers' enacted PCK.

The researcher proposes further studies to be conducted on the use of video-recorded lesson observations in capturing teachers' enacted PCK for specific concepts in Science. Novice teachers should receive coordinated induction programmes to enhance their understanding and interpretation of the syllabus in line with 21st century teaching. Furthermore, the pedagogical integration of smartphones and pre-selected YouTube videos during teaching and learning of abstract concepts such as EMI is another recommendation for further studies.

Given the challenges faced by teachers and learners in understanding EMI, I recommend to summarize findings from this study for the Department of Basic Education (DoBE) so that it can be distributed to in-service teachers for reference.

6.9 CONCLUSION

A mixed methods research approach was used in this study to investigate and explain the effects of a generic PCK intervention. The qualitative data collected from treatment group teachers assisted in tracking the development of the teachers' PCK while quantitative data from treatment and control group learners' baseline and post-test scores assisted in establishing the effect on learner performance.

There was an upward shift in scores from pre-CoRe scores to post-CoRe for all four treatment group teachers. The overall picture is that the post-CoRe scores were higher than those for the pre-CoRes. This gives the general impression that the teachers had gained PCK in completing their post-CoRes compared to pre-CoRes. Although there were some isolated cases where teachers faced challenges of incorrectly completing their post-CoRes, it can be deduced that the generic PCK intervention was transferred to teachers' pPCK development in the topic of EMI.

The overall enacted PCK scores were prevalently lower than those for the post-CoRes in most of the PCK components and for all the teachers. There is a general impression that the sampled teachers had some challenges of effectively enacting their PCK, especially for the second big idea of FL. However, the enacted PCK scores were higher than the pre-CoRe scores, indicating that the generic PCK intervention was successfully transferred to the topic of EMI. Several factors may have negatively impacted on teachers' PCK enactment such as skills to use appropriate apparatus or video. Ultimately, inadequate content knowledge clearly contributed to the relatively lower scores for ePCK on the topic of EMI. Furthermore, it is possible that the teachers did not make a conscious effort to use the CoRes as part of the lesson planning. Instead, they regarded the writing of the CoRes simply as an academic exercise for the sake of the research.

The quantitative results in this research study revealed that the post-test performance of learners from the experimental group schools were significantly better than those of learners from the control group schools, hence it can be concluded that the better performance of learners from the treatment group can be attributed to the generic PCK intervention on the treatment group teachers' PCK in EMI.

The result of this study reveals that the use of generic PCK intervention highlights the challenge of poor content knowledge exhibited by teachers. Despite such a challenge which can be overcome through continued professional development, this study reveals that generic PCK intervention assists in transferring PCK skills which enhance better learner performance, hence, the success of a generic PCK intervention as depicted by the result of this study outweighs its associated challenges.

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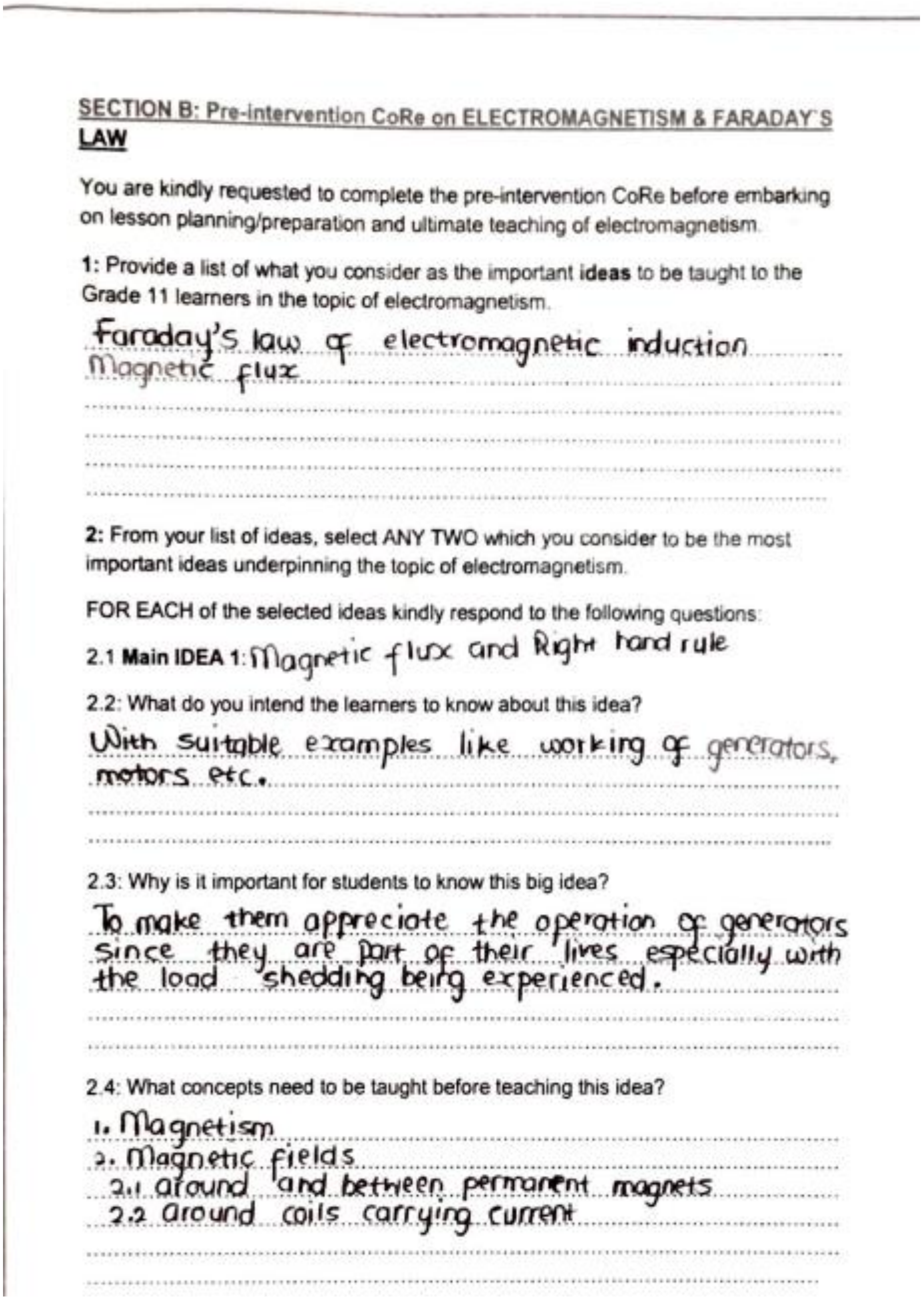
APPENDIX A1:TE1 COMPLETED PRE-INTERVENTION CoRe



SECTION B: Pre-intervention CoRe on ELECTROMAGNETISM & FARADAY'S LAW

You are kindly requested to complete the pre-intervention CoRe before embarking on lesson planning/preparation and ultimate teaching of electromagnetism.

1: Provide a list of what you consider as the important **ideas** to be taught to the Grade 11 learners in the topic of electromagnetism.

Faraday's law of electromagnetic induction
Magnetic flux

2: From your list of ideas, select ANY TWO which you consider to be the most important ideas underpinning the topic of electromagnetism.

FOR EACH of the selected ideas kindly respond to the following questions:

2.1 **Main IDEA 1:** Magnetic flux and Right hand rule

2.2: What do you intend the learners to know about this idea?

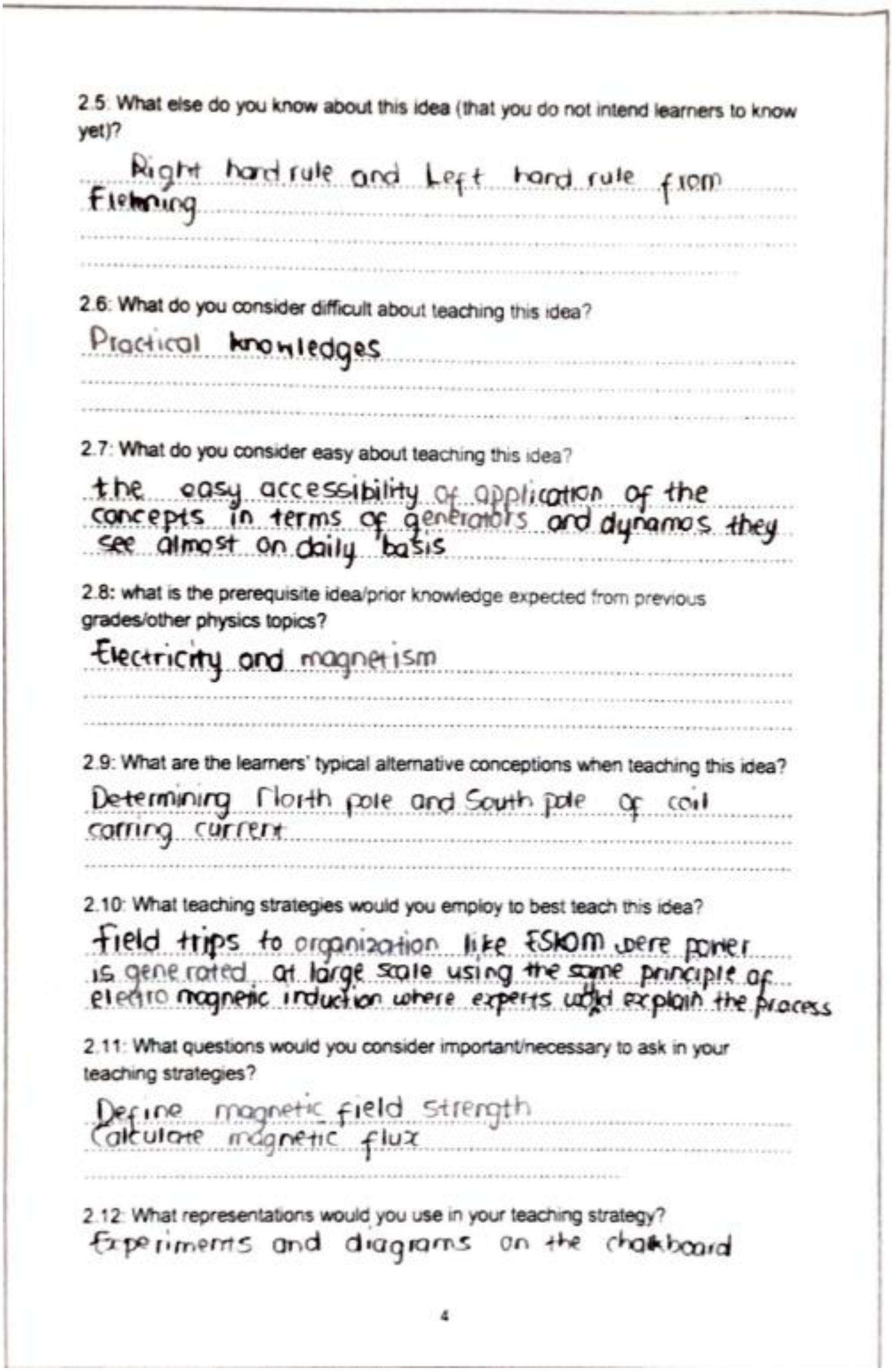
With suitable examples like working of generators, motors etc.

2.3: Why is it important for students to know this big idea?

To make them appreciate the operation of generators since they are part of their lives especially with the load shedding being experienced.

2.4: What concepts need to be taught before teaching this idea?

1. Magnetism
2. Magnetic fields
   2.1 around and between permanent magnets
   2.2 around coils carrying current



2.5: What else do you know about this idea (that you do not intend learners to know yet)?

Right hand rule and Left hand rule from Flemming

2.6: What do you consider difficult about teaching this idea?

Practical knowledges

2.7: What do you consider easy about teaching this idea?

the easy accessibility of application of the concepts in terms of generators and dynamos they see almost on daily basis

2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Electricity and magnetism

2.9: What are the learners' typical alternative conceptions when teaching this idea?

Determining North pole and South pole of coil carring current

2.10: What teaching strategies would you employ to best teach this idea?

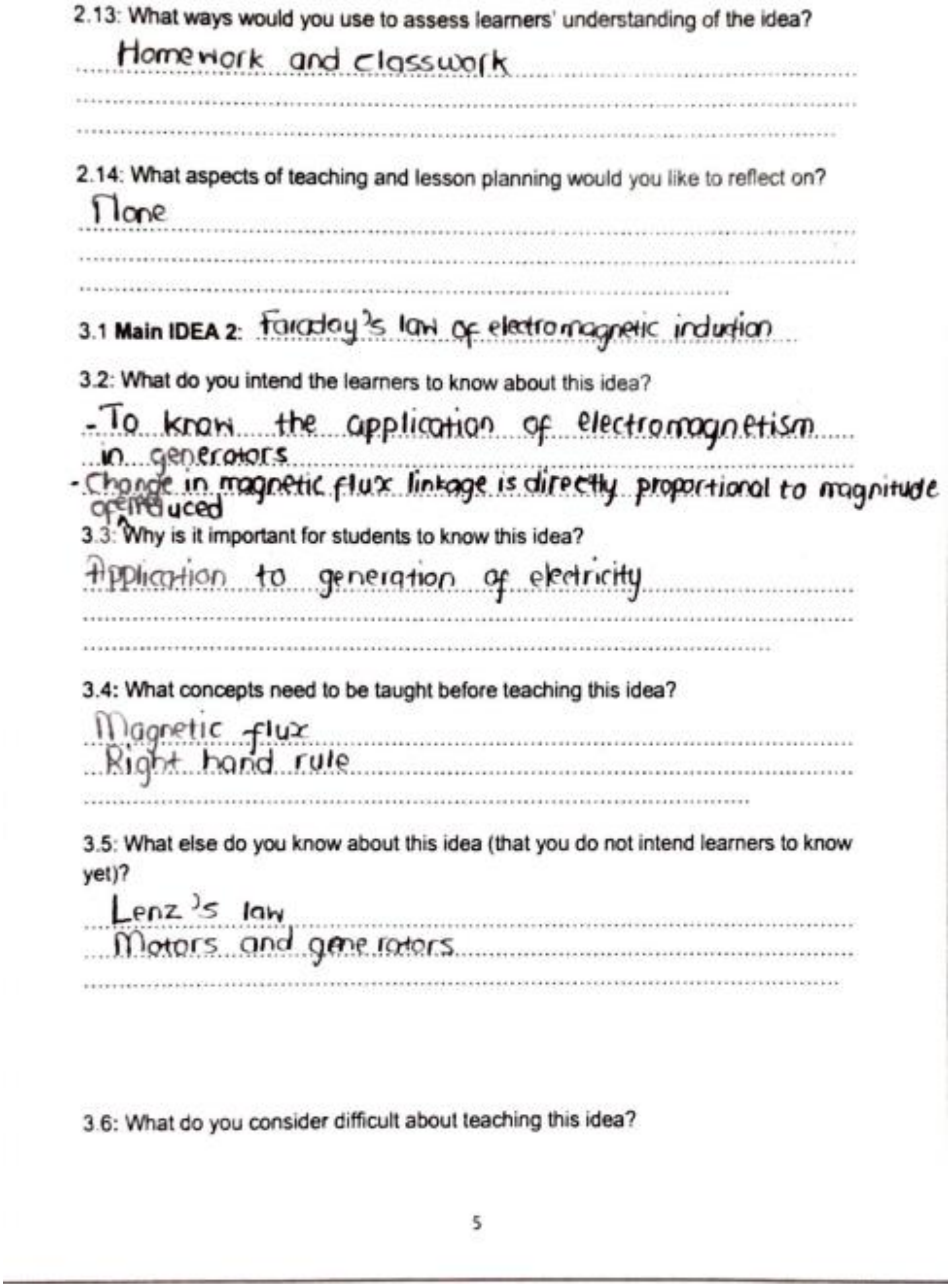
field trips to organization like ESKOM were power is generated at large scale using the same principle of electro magnetic induction where experts would explain the process

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

Define magnetic field strength
Calculate magnetic flux

2.12: What representations would you use in your teaching strategy?
Experiments and diagrams on the chalkboard

4



2.13: What ways would you use to assess learners' understanding of the idea?

Homework and classwork

2.14: What aspects of teaching and lesson planning would you like to reflect on?

None

3.1 **Main IDEA 2:** Faraday's law of electromagnetic induction

3.2: What do you intend the learners to know about this idea?

- To know the application of electromagnetism in generators
- Change in magnetic flux linkage is directly proportional to magnitude of emf induced

3.3: Why is it important for students to know this idea?

Application to generation of electricity

3.4: What concepts need to be taught before teaching this idea?

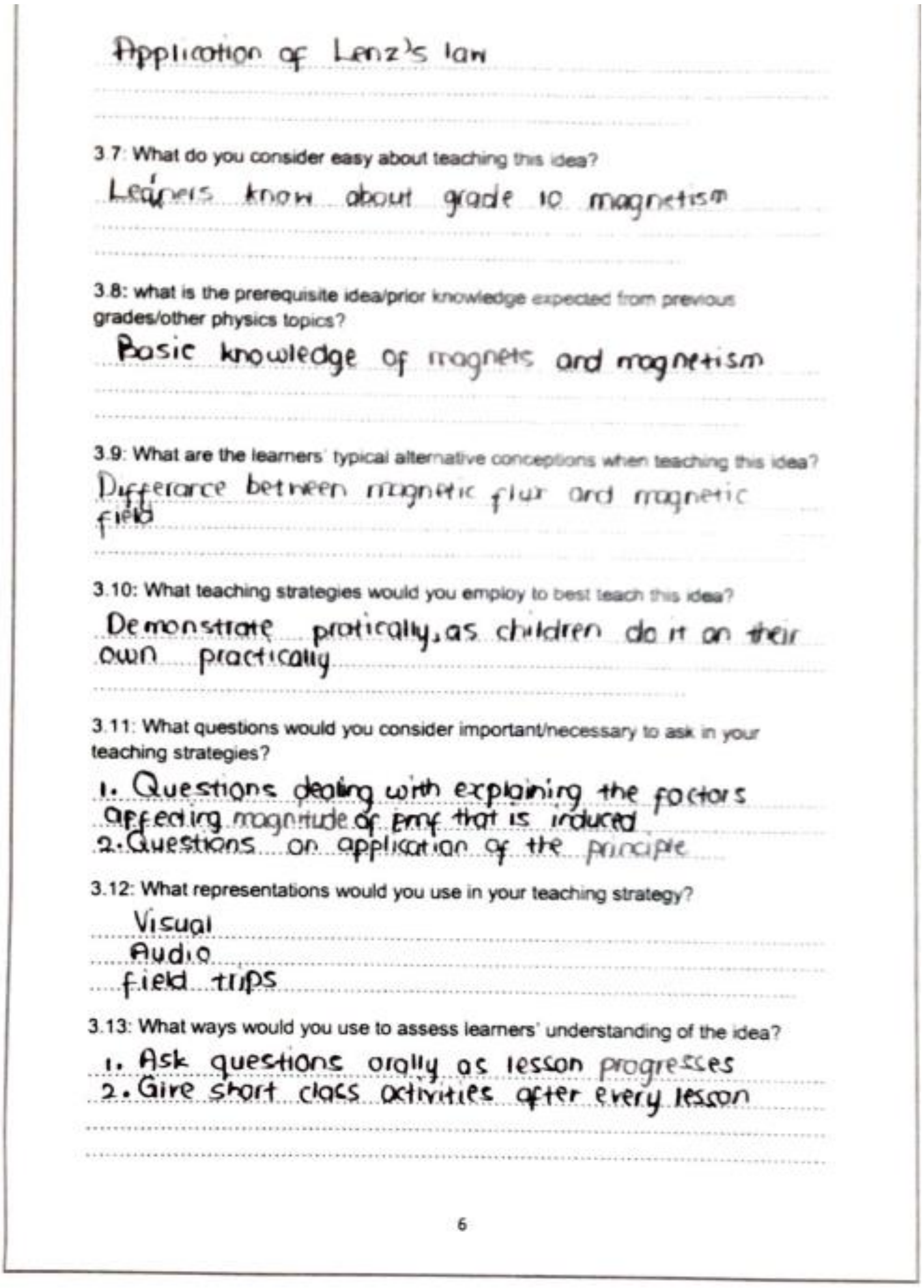
Magnetic flux
Right hand rule

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

Lenz's law
Motors and generators

3.6: What do you consider difficult about teaching this idea?

5


Application of Lenz's law

3.7: What do you consider easy about teaching this idea?

Learners know about grade 10 magnetism

3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Basic knowledge of magnets and magnetism

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Differance between magnetic flux and magnetic field

3.10: What teaching strategies would you employ to best teach this idea?

Demonstrate pratically, as children do it on their own practically

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

1. Questions dealing with explaining the factors affecting magnitude of emf that is induced
2. Questions on application of the principle

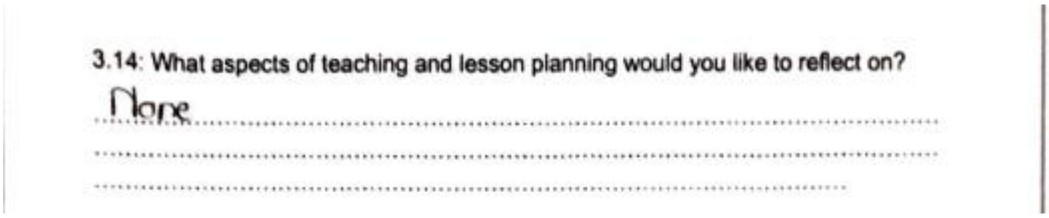
3.12: What representations would you use in your teaching strategy?

Visual
Audio
field trips

3.13: What ways would you use to assess learners' understanding of the idea?

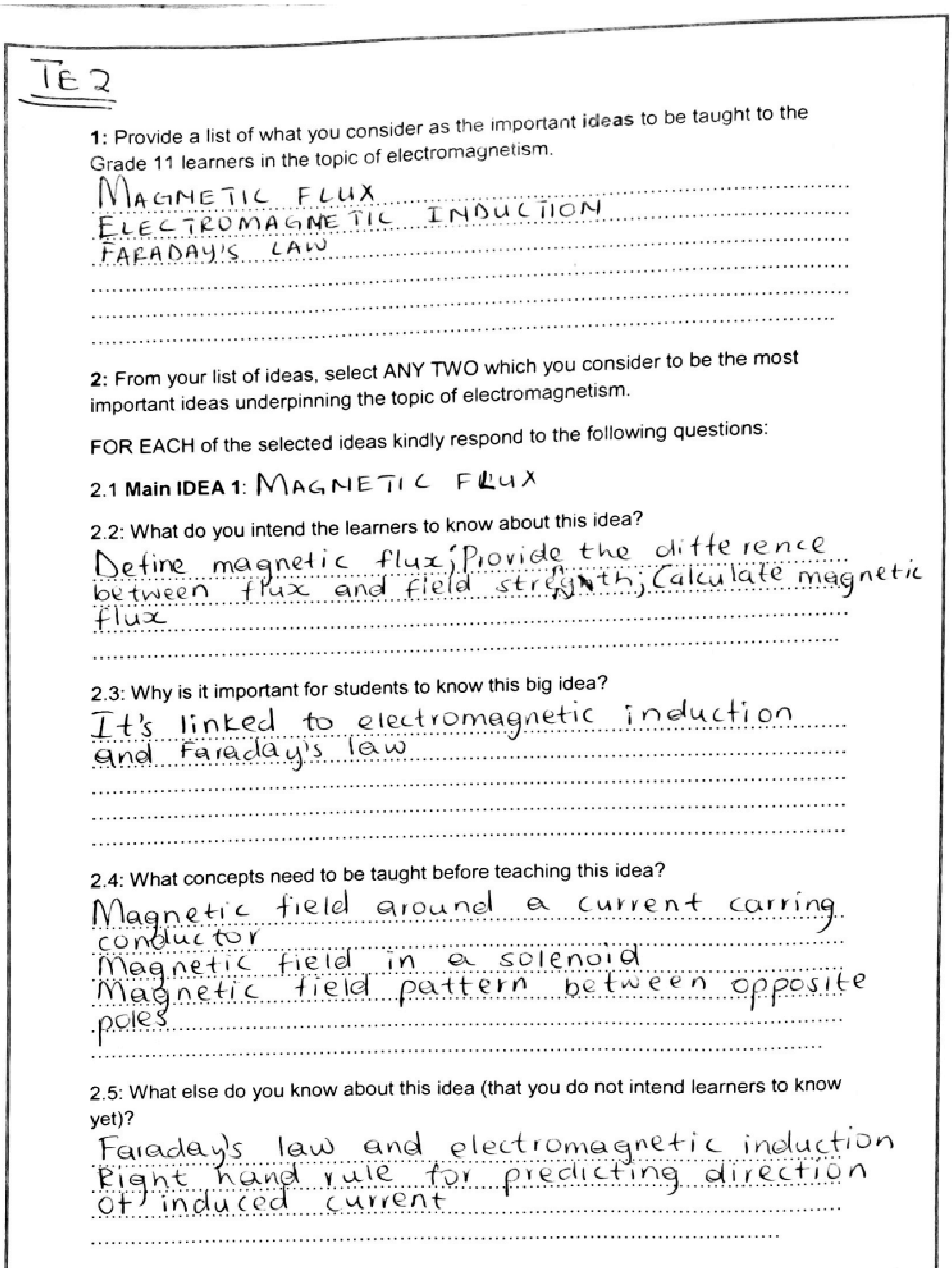
1. Ask questions orally as lesson progresses
2. Give short class activities after every lesson

6


3.14: What aspects of teaching and lesson planning would you like to reflect on?

None

APPENDIX A2: TE2 COMPLETED PRE-INTERVENTION CoRe



TE2

1: Provide a list of what you consider as the important **ideas** to be taught to the Grade 11 learners in the topic of electromagnetism.

MAGNETIC FLUX
ELECTROMAGNETIC INDUCTION
FARADAY'S LAW

2: From your list of ideas, select ANY TWO which you consider to be the most important ideas underpinning the topic of electromagnetism.

FOR EACH of the selected ideas kindly respond to the following questions:

2.1 **Main IDEA 1:** MAGNETIC FLUX

2.2: What do you intend the learners to know about this idea?

Define magnetic flux; Provide the difference between flux and field strength; Calculate magnetic flux

2.3: Why is it important for students to know this big idea?

It's linked to electromagnetic induction and Faraday's law

2.4: What concepts need to be taught before teaching this idea?

Magnetic field around a current carring conductor
Magnetic field in a solenoid
Magnetic field pattern between opposite poles

2.5: What else do you know about this idea (that you do not intend learners to know yet)?

Faraday's law and electromagnetic induction
Right hand rule for predicting direction of induced current

2.6: What do you consider difficult about teaching this idea?

Differiatiting between flux and field strength.
Demonstrating experimental the existance of flux

2.7: What do you consider easy about teaching this idea?

Calculating magnetic flux
Recalling the SI units of flux and field strength.

2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic field patterns around permanent magnets
Behaviour of magnetic campass near magnetic pole.

2.9: What are the learners' typical alternative conceptions when teaching this idea?

Magnetic field lines start from the North pole and end at the south pole
Misinterpretation and misunderstanding of domain theory.

2.10: What teaching strategies would you employ to best teach this idea?

Illustrate using chalkboard diagrams and work sheets the physics of magnetic flux and angle θ

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

Define magnetic field strength; suggest physical difference between flux and field strength; How would you calculate change in flux

2.12: What representations would you use in your teaching strategy?

Chalkboard diagrams illustrating flux and angle
Practical demonstration or simulation of flux

2.13: What ways would you use to assess learners' understanding of the idea?

Assessment based on flux calculations and flux change; Difference between field strength and flux

2.14: What aspects of teaching and lesson planning would you like to reflect on?

Reflect on magnetic field around solenoid
and straight conductor

3.1 **Main IDEA 2**: Faraday's law of electromagnetic
induction

3.2: What do you intend the learners to know about this idea?

Induced emf is directly proportional to rate of
change in magnetic flux, Relative motion
Lenz's law

3.3: Why is it important for students to know this idea?

Production of emf relies on changing magnetic
flux

3.4: What concepts need to be taught before teaching this idea?

Right hand rule; Magnetic flux
Change in magnetic flux
Relative motion between magnet and coil

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

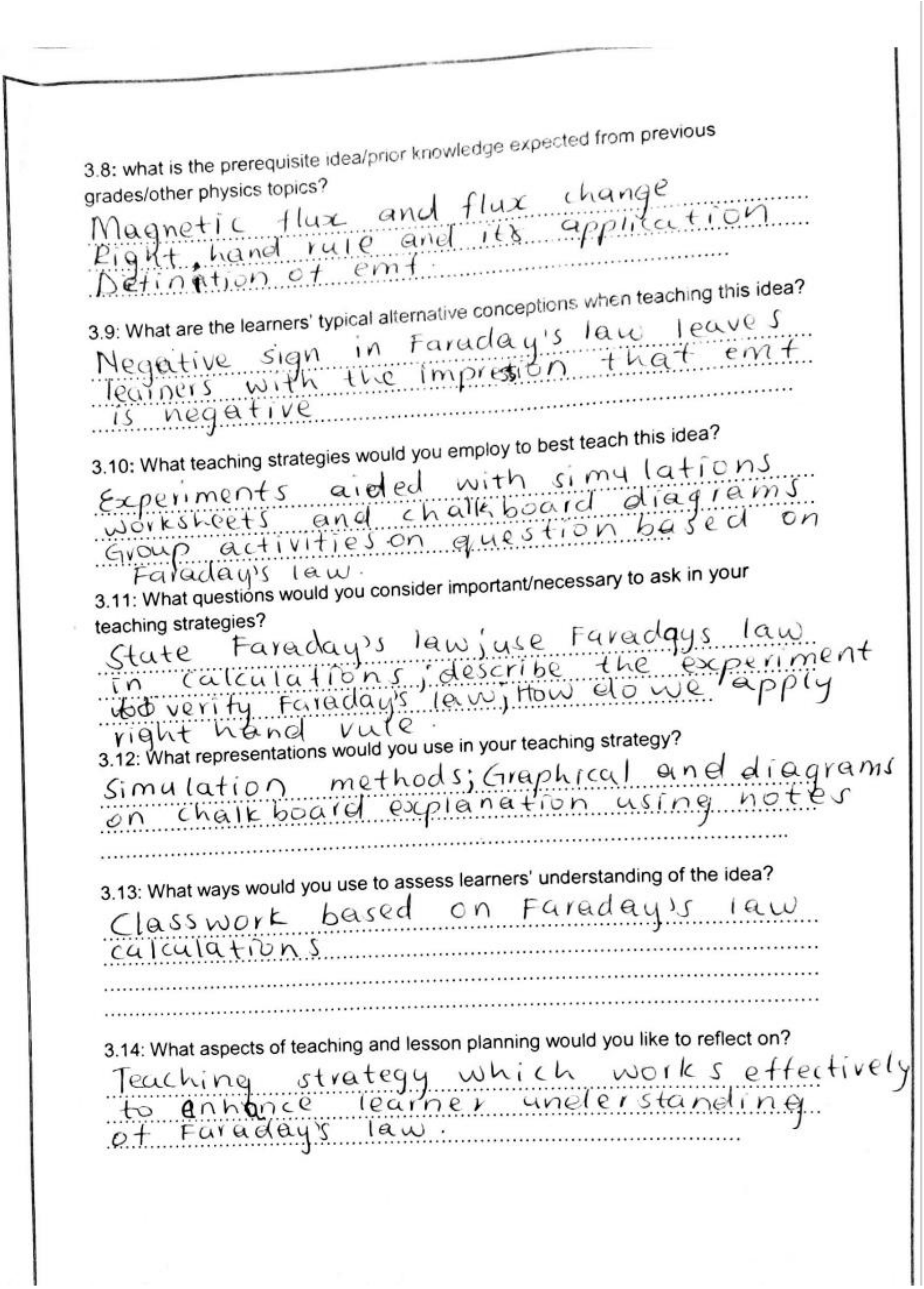
Right hand rule is used to predict
direction of induced current and works
in line with Lenz's law

3.6: What do you consider difficult about teaching this idea?

Explain Lenz's law to Foster learner
understanding of direction of induced
current; Explain Faraday's law without
label equipment

3.7: What do you consider easy about teaching this idea?

Demonstrating electromagnetic induction
using simulations



3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic flux and flux change
Right hand rule and its application
Definition of emf.

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Negative sign in Faraday's law leaves learners with the impression that emf is negative

3.10: What teaching strategies would you employ to best teach this idea?

Experiments aided with simulations worksheets and chalkboard diagrams Group activities on question based on Faraday's law.

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

State Faraday's law; use Faradays law in calculations; describe the experiment to verify Faraday's law; How do we apply right hand rule.

3.12: What representations would you use in your teaching strategy?

Simulation methods; Graphical and diagrams on chalkboard explanation using notes

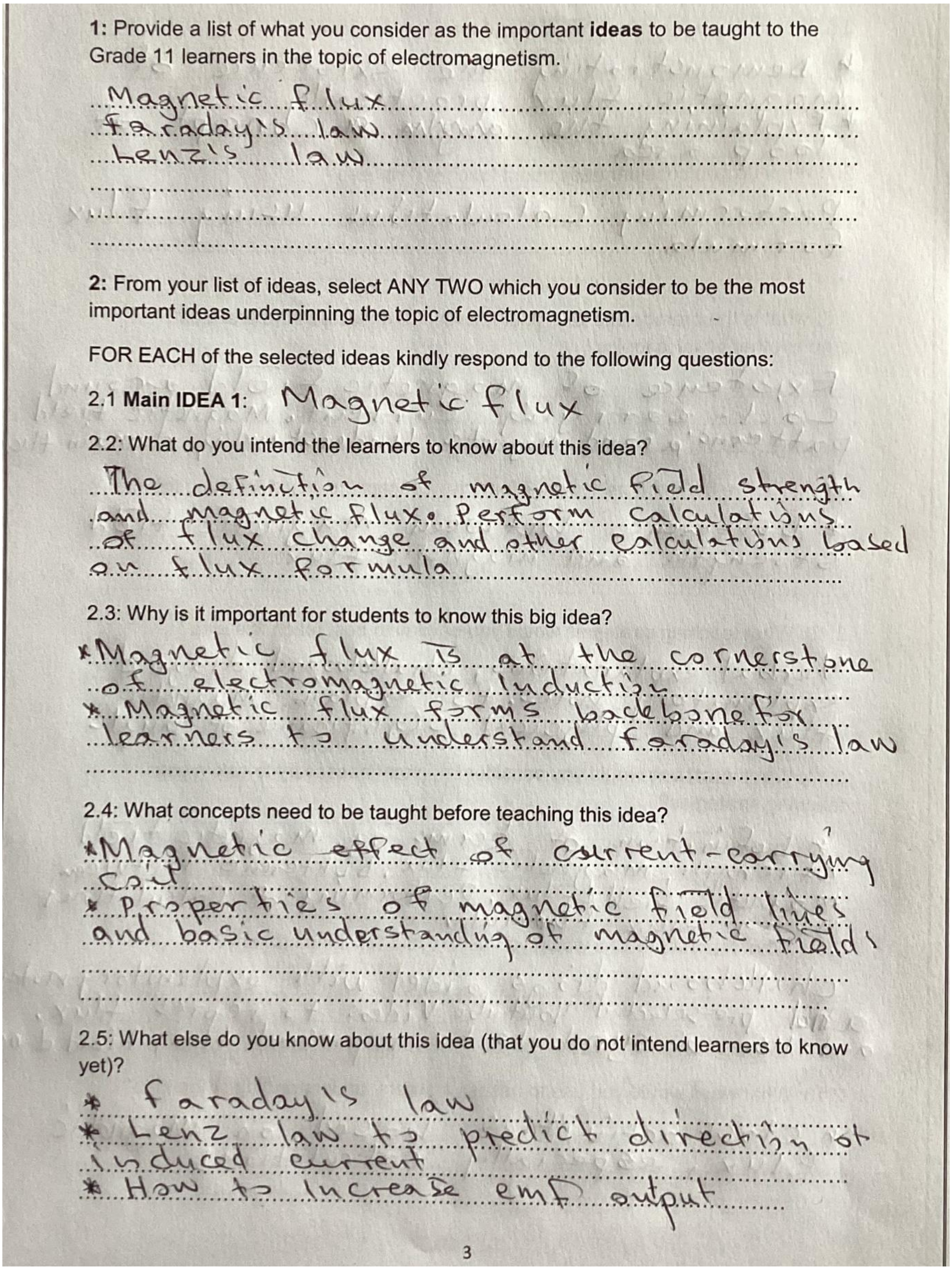
3.13: What ways would you use to assess learners' understanding of the idea?

Classwork based on Faraday's law calculations

3.14: What aspects of teaching and lesson planning would you like to reflect on?

Teaching strategy which works effectively to enhance learner understanding of Faraday's law.

APPENDIX A3: TE3 COMPLETED PRE-INTERVENTION CoRe



1: Provide a list of what you consider as the important **ideas** to be taught to the Grade 11 learners in the topic of electromagnetism.

Magnetic flux
faraday's law
Lenz's law

2: From your list of ideas, select ANY TWO which you consider to be the most important ideas underpinning the topic of electromagnetism.

FOR EACH of the selected ideas kindly respond to the following questions:

2.1 **Main IDEA 1**: Magnetic flux

2.2: What do you intend the learners to know about this idea?

The definition of magnetic field strength and magnetic flux. Perform calculations of flux change and other calculations based on flux formula

2.3: Why is it important for students to know this big idea?

*Magnetic flux is at the cornerstone of electromagnetic induction
*Magnetic flux forms backbone for learners to understand faraday's law

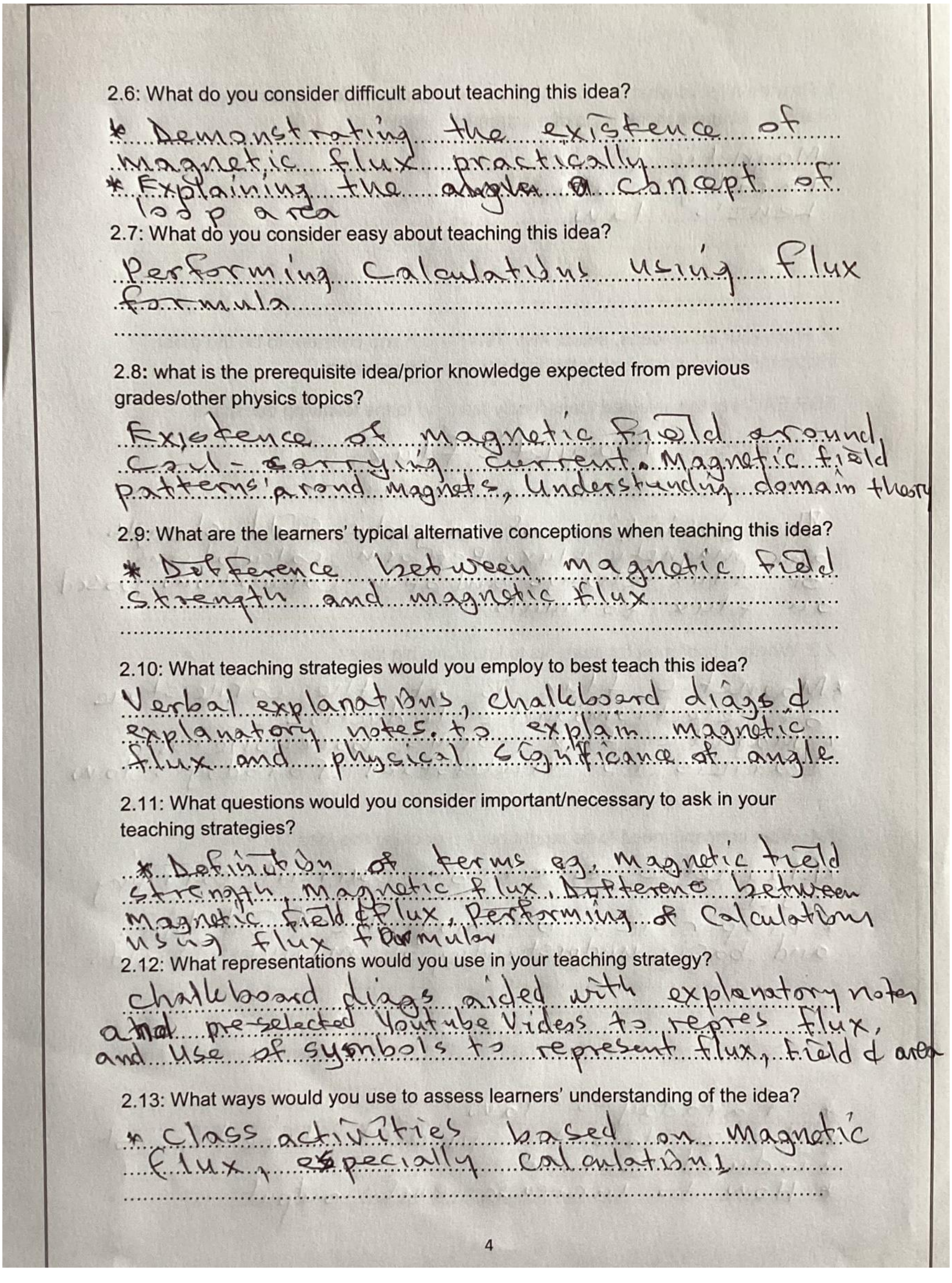
2.4: What concepts need to be taught before teaching this idea?

*Magnetic effect of current-carrying coil
*Properties of magnetic field lines and basic understanding of magnetic fields

2.5: What else do you know about this idea (that you do not intend learners to know yet)?

* faraday's law
* Lenz law to predict direction of induced current
* How to increase emf output

3



2.6: What do you consider difficult about teaching this idea?

* Demonstrating the existence of magnetic flux practically
* Explaining the ~~angle~~ concept of loop area

2.7: What do you consider easy about teaching this idea?

Performing calculations using flux formula

2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Existence of magnetic field around coil-carrying current. Magnetic field patterns arond magnets, Understanding domain theory

2.9: What are the learners' typical alternative conceptions when teaching this idea?

* Difference between magnetic field strength and magnetic flux

2.10: What teaching strategies would you employ to best teach this idea?

Verbal explanations, chalkboard diags & explanatory notes to explain magnetic flux and physical significance of angle

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

* Definition of terms eg. magnetic field strength, magnetic flux. Difference between magnetic field & flux, Performing of calculations using flux formula

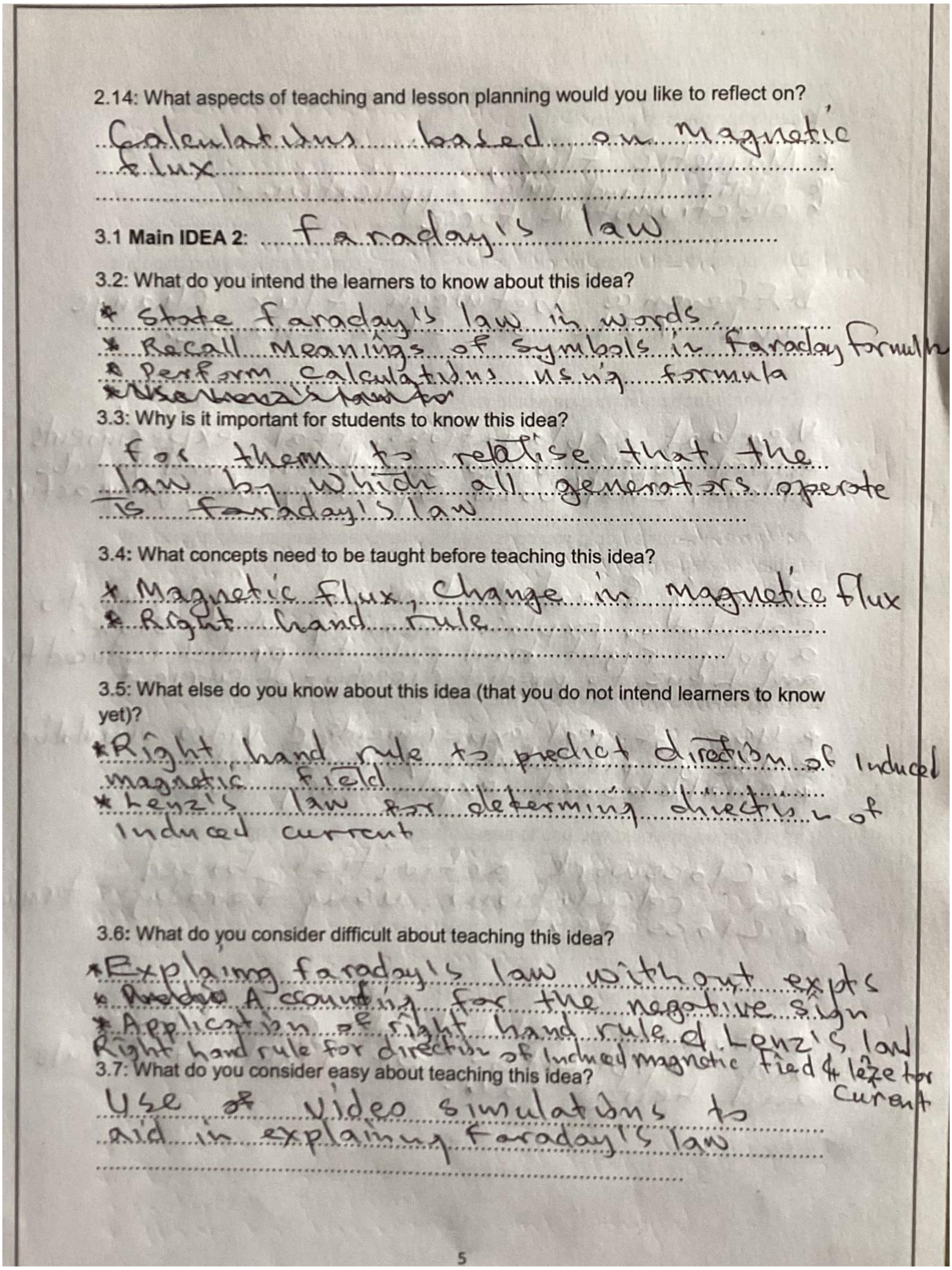
2.12: What representations would you use in your teaching strategy?

chalkboard diags aided with explanatory notes and pre-selected Youtube Videos to repres flux, and use of symbols to represent flux, field & area

2.13: What ways would you use to assess learners' understanding of the idea?

* class activities based on magnetic flux, especially calculations

4



2.14: What aspects of teaching and lesson planning would you like to reflect on?

Calculations based on magnetic flux

3.1 **Main IDEA 2:** faraday's law

3.2: What do you intend the learners to know about this idea?

* State faraday's law in words.
* Recall Meanings of symbols in faraday formula
* Perform calculations using formula
* ~~Use Lenz's law for~~

3.3: Why is it important for students to know this idea?

for them to realise that the law by which all generators operate is faraday's law

3.4: What concepts need to be taught before teaching this idea?

* Magnetic flux, change in magnetic flux
* Right hand rule

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

* Right hand rule to predict direction of induced magnetic field
* Lenz's law for determing direction of induced current

3.6: What do you consider difficult about teaching this idea?

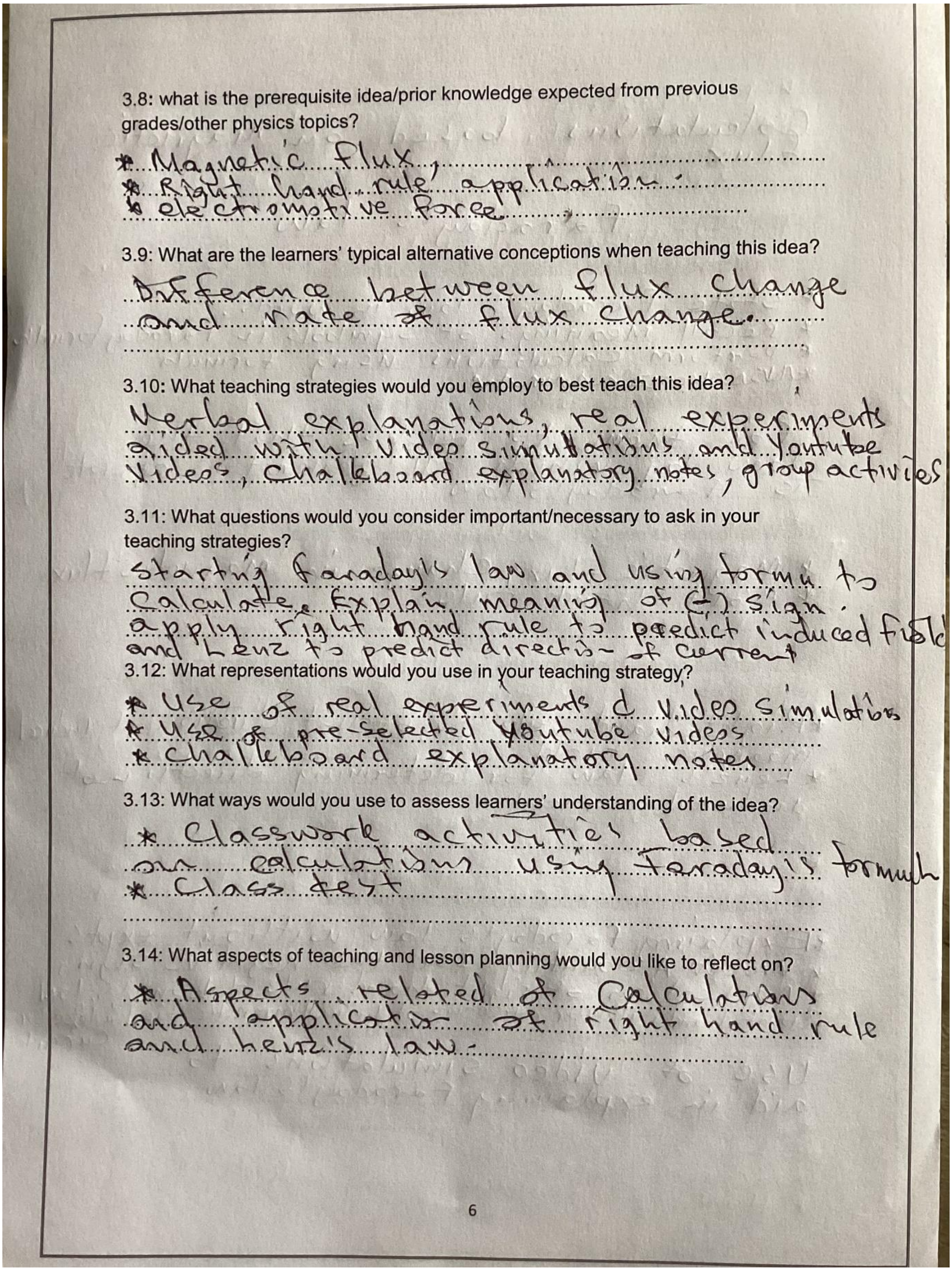
* Explaing faraday's law without expts
* ~~Predic~~ Accounting for the negative sign
* Application of right hand rule & Lenz's law

Right hand rule for direction of induced magnetic fied & lenze for curent

3.7: What do you consider easy about teaching this idea?

Use ~~of~~ video simulations to aid in explaining faraday's law

5



3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

* Magnetic flux,
* Right hand rule application.
* electromotive force

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Difference between flux change and rate of flux change.

3.10: What teaching strategies would you employ to best teach this idea?

Verbal explanations, real experiments aided with video simulations and Youtube videos, chalkboard explanatory notes, group activities

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

starting Faraday's law and using formu to Calculate. Explain meaning of (-) sign. apply right hand rule to predict induced field and Lenz to predict direction of current

3.12: What representations would you use in your teaching strategy?

* Use of real experiments & video simulations
* Use of pre-selected Youtube videos
* Chalkboard explanatory notes

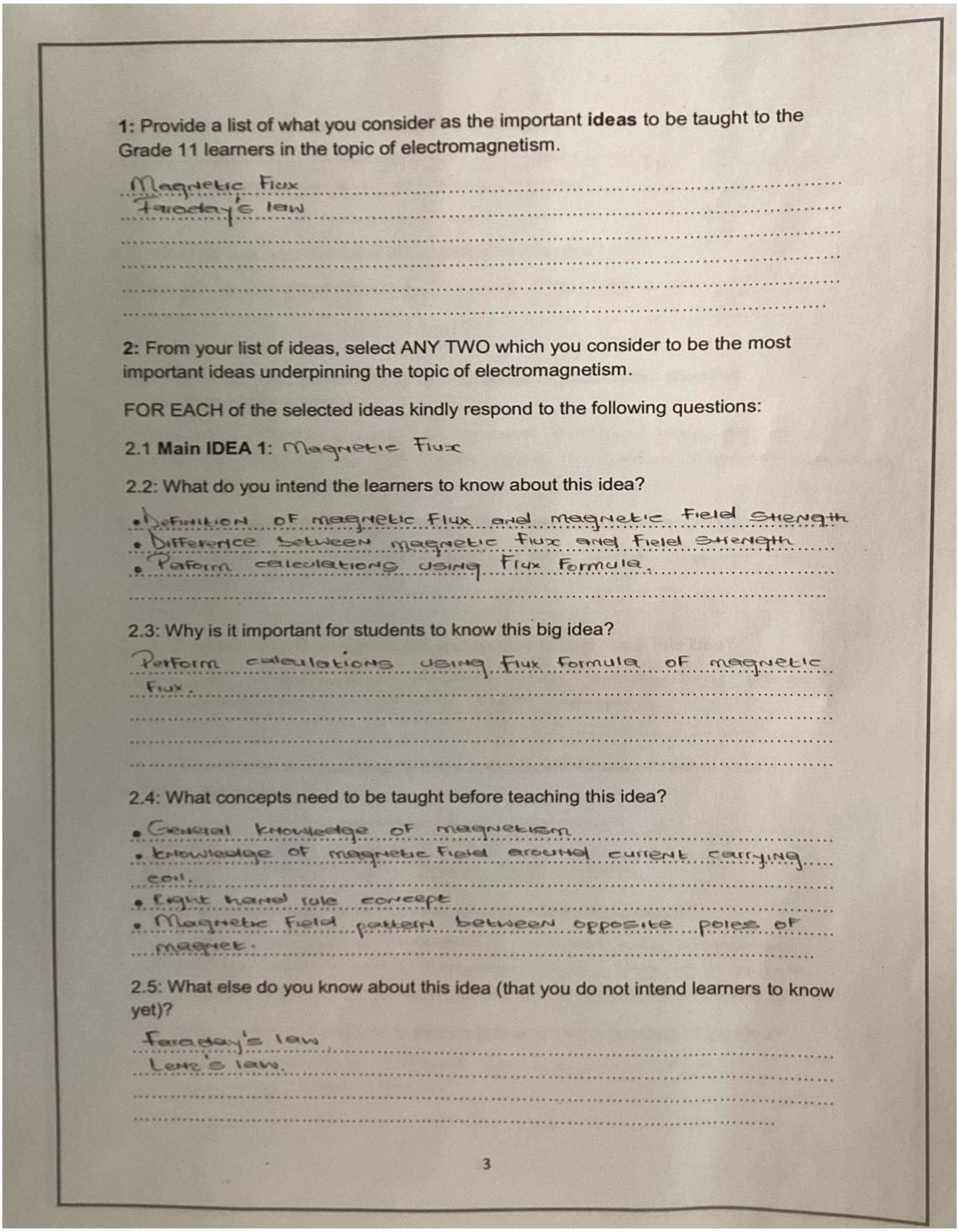
3.13: What ways would you use to assess learners' understanding of the idea?

* Classwork activities based on calculations using Faraday's formula
* Class test

3.14: What aspects of teaching and lesson planning would you like to reflect on?

* Aspects related of Calculations and application of right hand rule and Lenz's law.

APPENDIX A4: TE4 COMPLETED PRE-INTERVENTION CoRe



1: Provide a list of what you consider as the important **ideas** to be taught to the Grade 11 learners in the topic of electromagnetism.

Magnetic Flux
Faraday's law

2: From your list of ideas, select ANY TWO which you consider to be the most important ideas underpinning the topic of electromagnetism.

FOR EACH of the selected ideas kindly respond to the following questions:

2.1 **Main IDEA 1:** Magnetic Flux

2.2: What do you intend the learners to know about this idea?

- Definition of magnetic Flux and magnetic field strength
- Difference between magnetic flux and field strength
- Paform calculations using Flux Formula.

2.3: Why is it important for students to know this big idea?

Perform calculations using flux formula of magnetic flux.

2.4: What concepts need to be taught before teaching this idea?

- General knowledge of magnetism
- knowledge of magnetic field around current carrying coil.
- right hand rule concept
- Magnetic field pattern between opposite poles of magnet.

2.5: What else do you know about this idea (that you do not intend learners to know yet)?

Faraday's law
Lenz's law.

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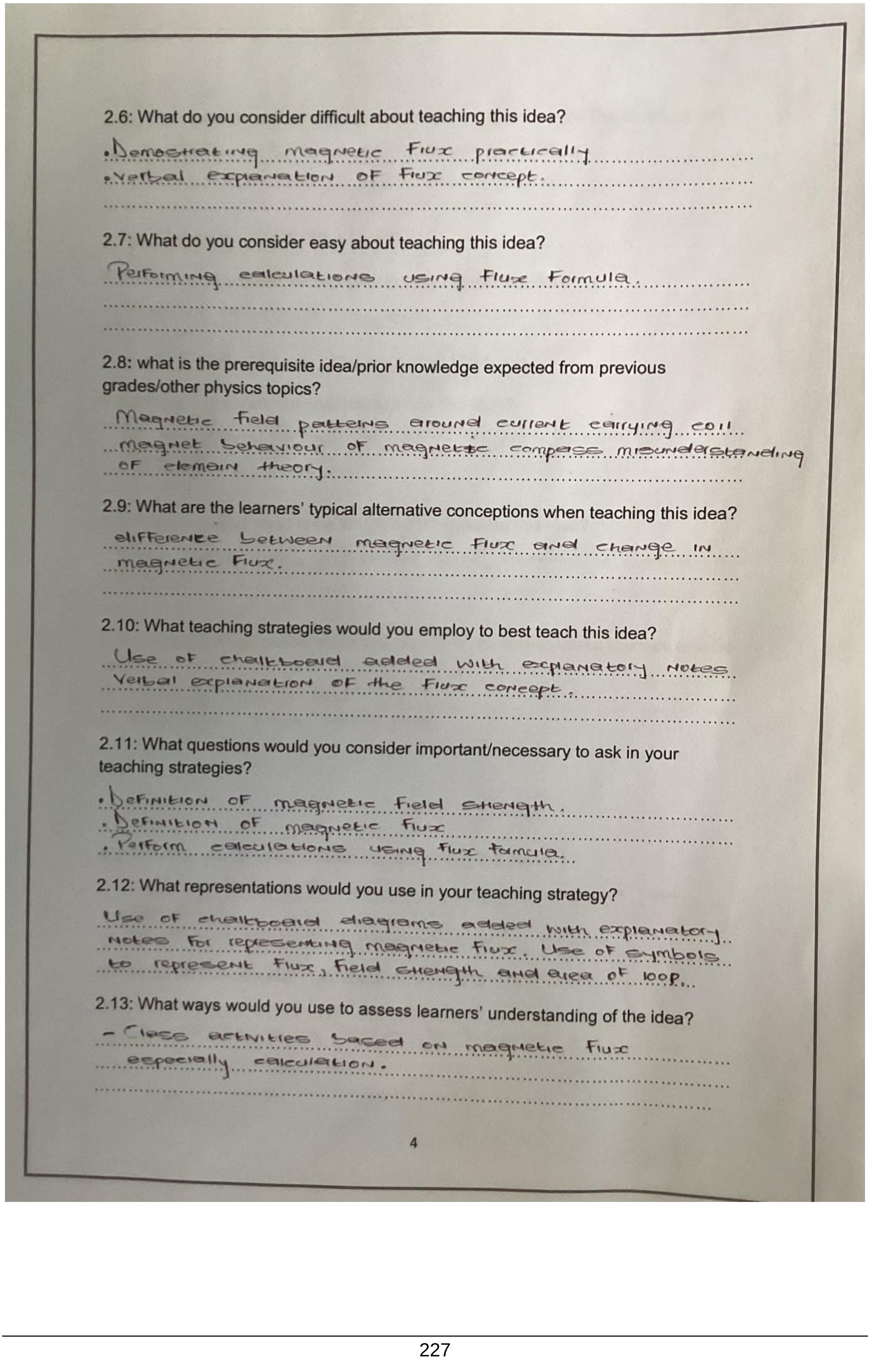

2.6: What do you consider difficult about teaching this idea?

•Demostrating magnetic flux practically
•Verbal explanation of flux concept.

2.7: What do you consider easy about teaching this idea?

Performing calculations using flux formula.

2.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic field patterns around current carrying coil magnet behaviour of magnetic compass misunderstanding of demain theory.

2.9: What are the learners' typical alternative conceptions when teaching this idea?

difference between magnetic flux and change in magnetic flux.

2.10: What teaching strategies would you employ to best teach this idea?

Use of chalkboard added with explanatory notes
Verbal explanation of the flux concept.

2.11: What questions would you consider important/necessary to ask in your teaching strategies?

•Definition of magnetic field strength.
•Definition of magnetic flux
•Perform calculations using flux formula.

2.12: What representations would you use in your teaching strategy?

Use of chalkboard diagrams added with explanatory notes for representing magnetic flux. Use of symbols to represent flux, field strength and area of loop.

2.13: What ways would you use to assess learners' understanding of the idea?

- Class activities based on magnetic flux especially calculation.

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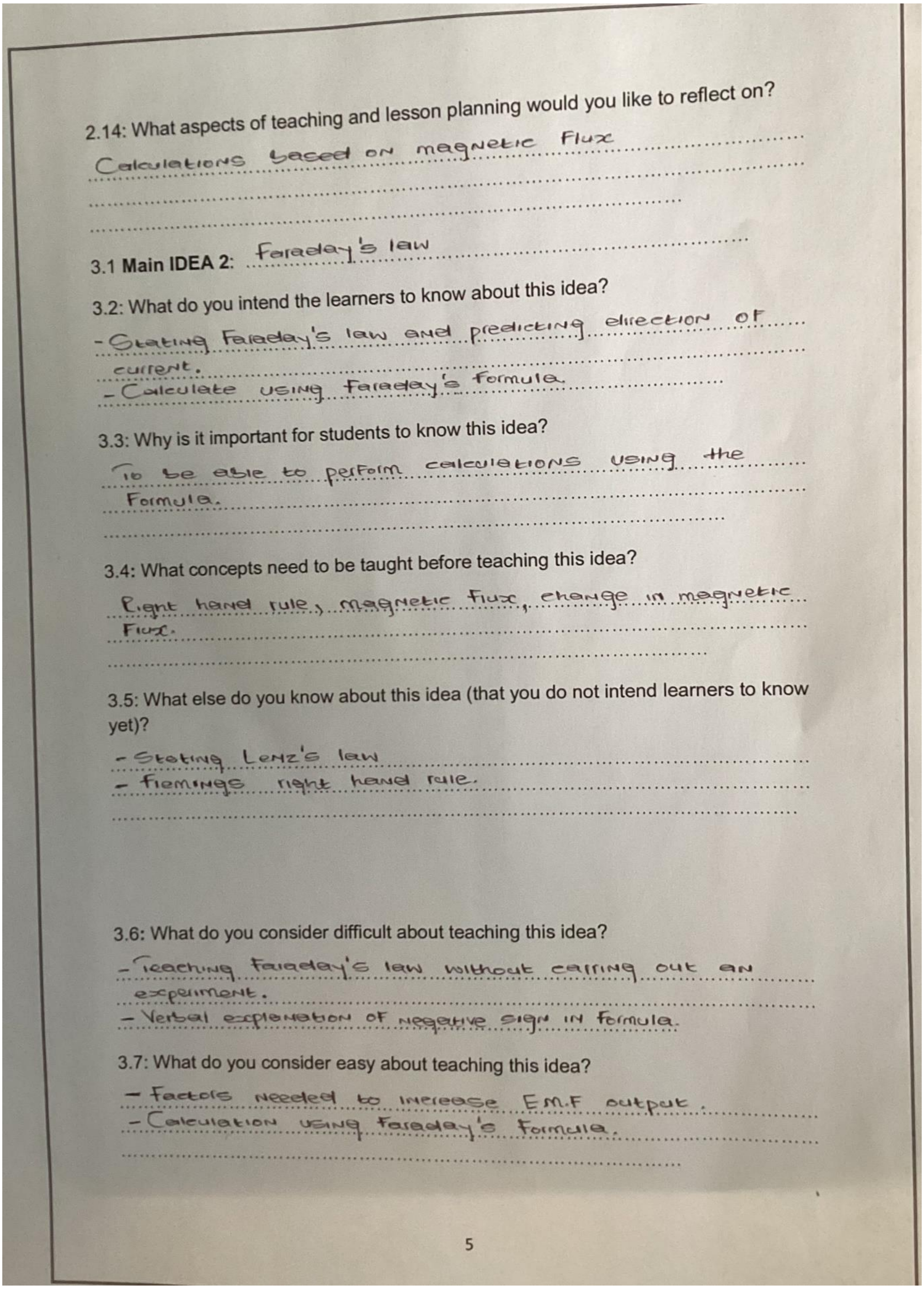


2.14: What aspects of teaching and lesson planning would you like to reflect on?

Calculations based on magnetic Flux

3.1 **Main IDEA 2:** Faraday's law

3.2: What do you intend the learners to know about this idea?

- Stating Faraday's law and predicting direction of current.
- Calculate using Faraday's Formula

3.3: Why is it important for students to know this idea?

To be able to perform calculations using the Formula.

3.4: What concepts need to be taught before teaching this idea?

Right hand rule, magnetic Flux, change in magnetic Flux.

3.5: What else do you know about this idea (that you do not intend learners to know yet)?

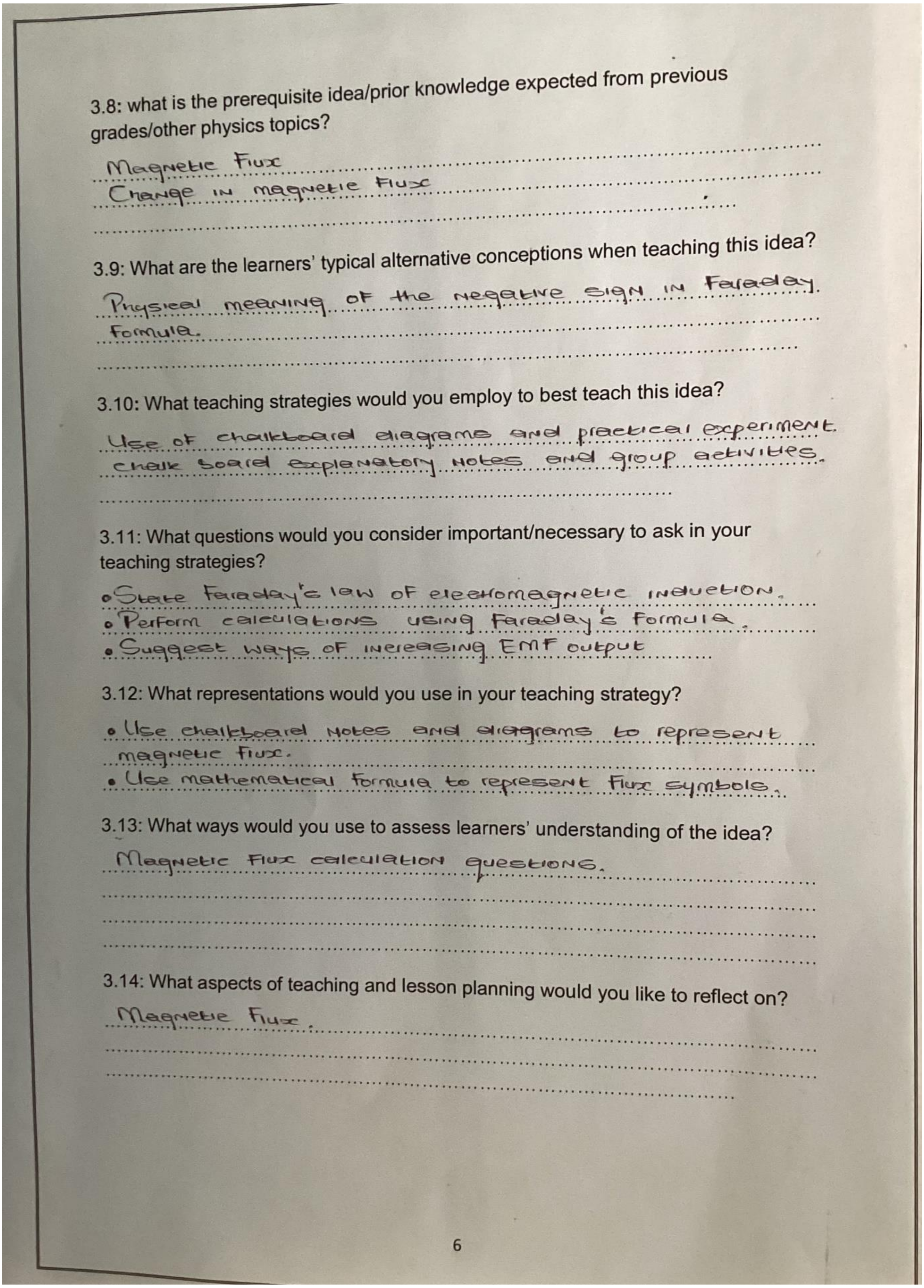
- Stating Lenz's law
- Flemings right hand rule.

3.6: What do you consider difficult about teaching this idea?

- Teaching Faraday's law without carring out an experiment.
- Verbal explanation of negative sign in formula.

3.7: What do you consider easy about teaching this idea?

- Factors needed to increase E.M.F output.
- Calculation using Faraday's Formula.



3.8: what is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?

Magnetic Flux
Change in magnetic Flux

3.9: What are the learners' typical alternative conceptions when teaching this idea?

Physical meaning of the negative sign in Faraday formula.

3.10: What teaching strategies would you employ to best teach this idea?

Use of chalkboard diagrams and practical experiment.
chalk board explanatory notes and group activities.

3.11: What questions would you consider important/necessary to ask in your teaching strategies?

- State Faraday's law of electromagnetic induction.
- Perform calculations using Faraday's formula.
- Suggest ways of increasing EMF output

3.12: What representations would you use in your teaching strategy?

- Use chalkboard notes and diagrams to represent magnetic flux.
- Use mathematical formula to represent flux symbols.

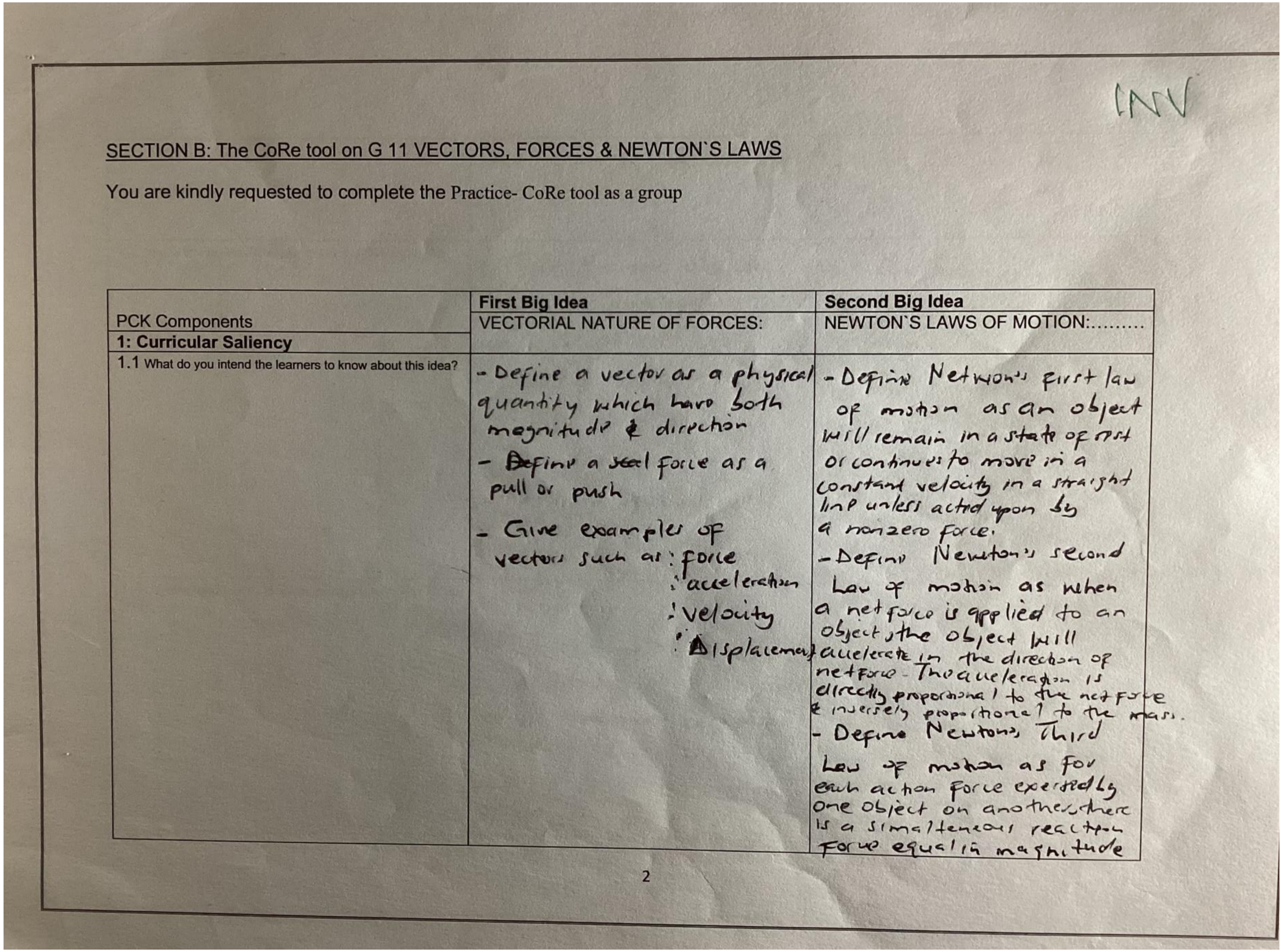
3.13: What ways would you use to assess learners' understanding of the idea?

Magnetic Flux calculation questions.

3.14: What aspects of teaching and lesson planning would you like to reflect on?

Magnetic Flux.

APPENDIX B: THE COMPLETED INTERVENTION CoRe



INV

SECTION B: The CoRe tool on G 11 VECTORS, FORCES & NEWTON`S LAWS

You are kindly requested to complete the Practice- CoRe tool as a group

PCK Components	First Big Idea VECTORIAL NATURE OF FORCES:	Second Big Idea NEWTON`S LAWS OF MOTION:………
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	- Define a vector as a physical quantity which have both magnitude & direction - Define a ~~seal~~ force as a pull or push - Give examples of vectors such as: force : acceleration : velocity : Displacement	- Define Netwon's first law of motion as an object will remain in a state of rest or continues to move in a constant velocity in a straight line unless acted upon by a nonzero force. - Define Newton's second Law of motion as when a net force is applied to an object, the object will accelerate in the direction of net force. The acceleration is directly proportional to the net force & inversely proportional to the mass. - Define Newtons Third Law of motion as for each action force exerted by one object on another, there is a simaltenous reaction force equal in magnitude

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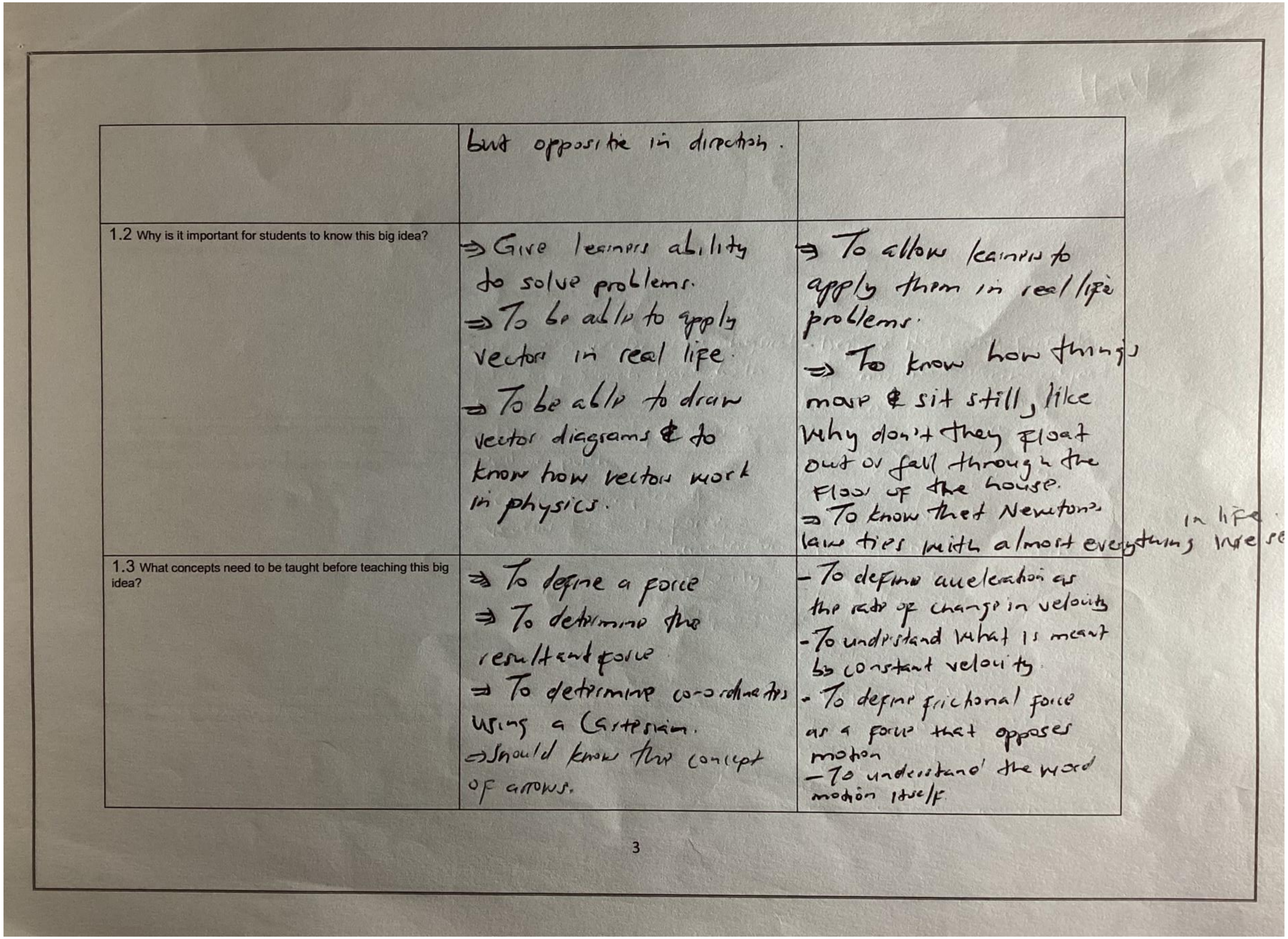

	but opposite in direction.	
1.2 Why is it important for students to know this big idea?	⇒ Give learners ability to solve problems. ⇒ To be able to apply vectors in real life. ⇒ To be able to draw vector diagrams & to know how vectors work in physics.	⇒ To allow learners to apply them in real life problems. ⇒ To know how things move & sit still, like why don't they float out or fall through the floor of the house. ⇒ To know that Newton's law ties with almost everything we se in life.
1.3 What concepts need to be taught before teaching this big idea?	⇒ To define a force ⇒ To determine the resultant force. ⇒ To determine co-ordinates using a Cartesian. ⇒ Should know the concept of arrows.	- To define acceleration as the rate of change in velocity - To understand what is meant by constant velocity. - To define frictional force as a force that opposes motion - To understand the word motion itself.

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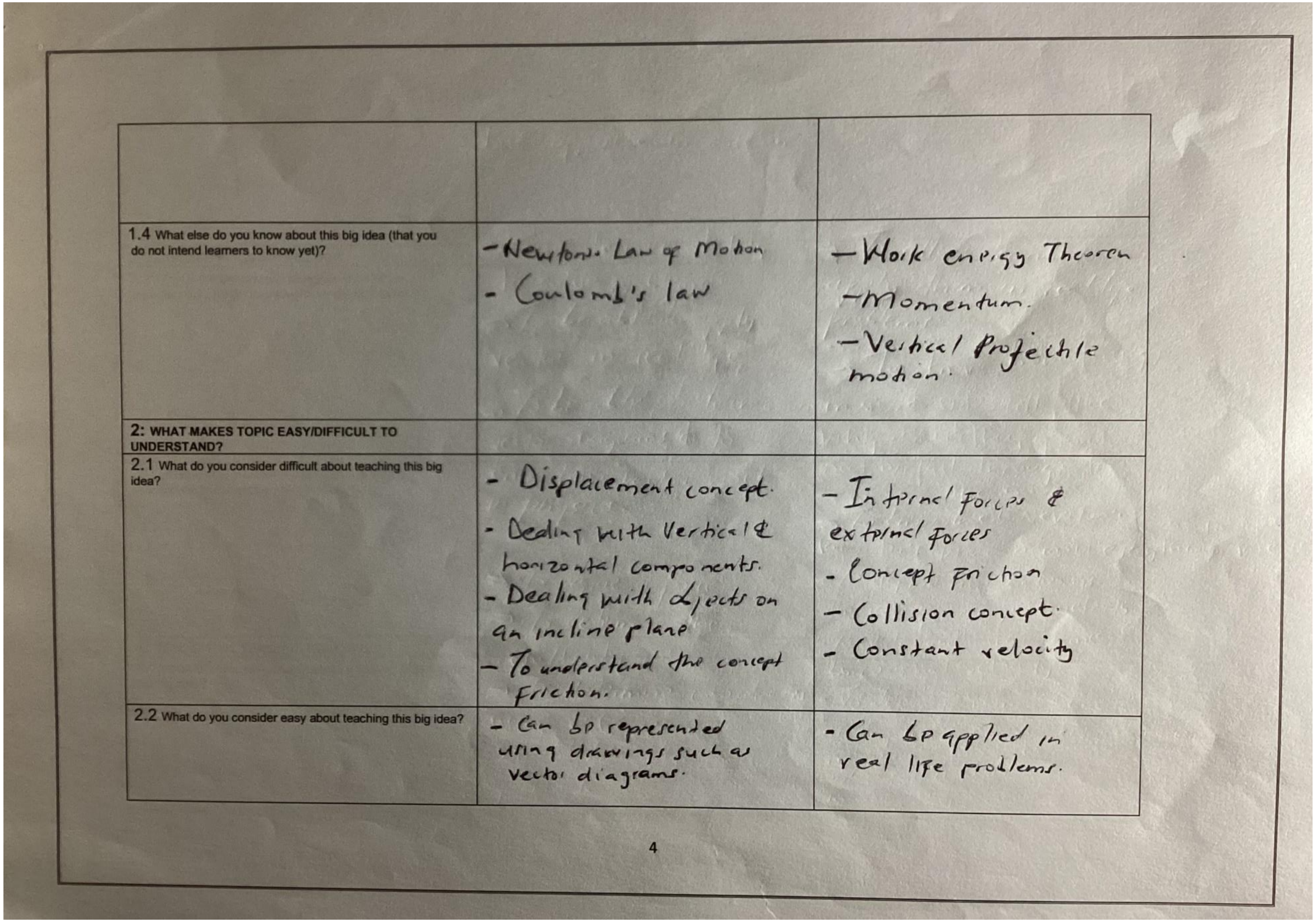
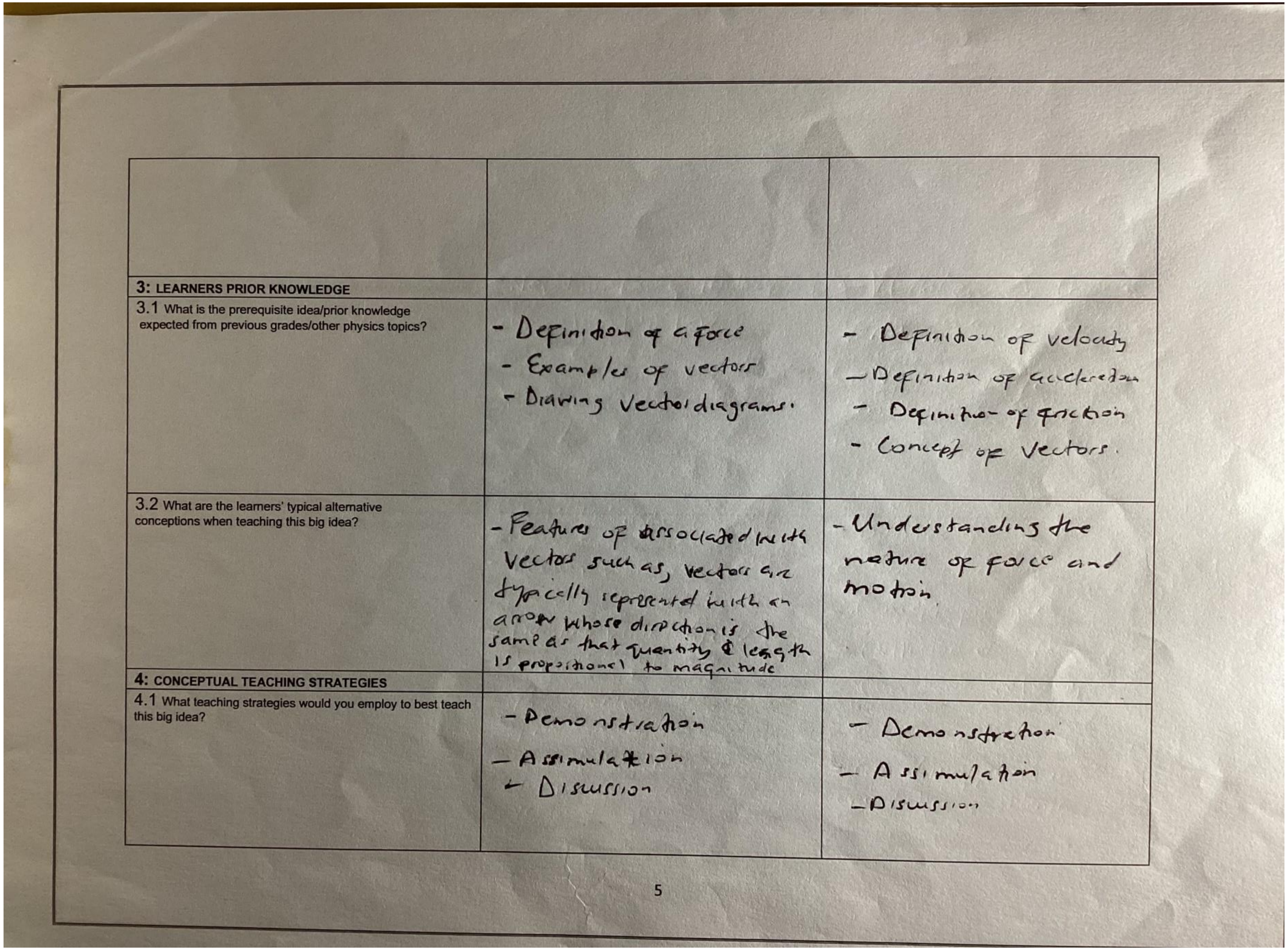


1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	- Newton's Law of Motion - Coulomb's law	- Work energy Theorem - Momentum. - Vertical Projectile motion.
2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea?	- Displacement concept. - Dealing with Vertical & horizontal components. - Dealing with objects on an incline plane - To understand the concept Friction.	- Internal Forces & external Forces - Concept friction - Collision concept. - Constant velocity
2.2 What do you consider easy about teaching this big idea?	- Can be represented using drawings such as vector diagrams.	- Can be applied in real life problems.



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	- Definition of a force - Examples of vectors - Drawing vector diagrams.	- Definition of velocity - Definition of acceleration - Definition of friction - Concept of vectors.
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	- Features of associated with vectors such as, vectors are typically represented with an arrow whose direction is the same as that quantity & length is proportional to magnitude	- Understanding the nature of force and motion.
4: CONCEPTUAL TEACHING STRATEGIES		
4.1 What teaching strategies would you employ to best teach this big idea?	- Demonstration - Assimulation - Discussion	- Demonstration - Assimulation - Discussion

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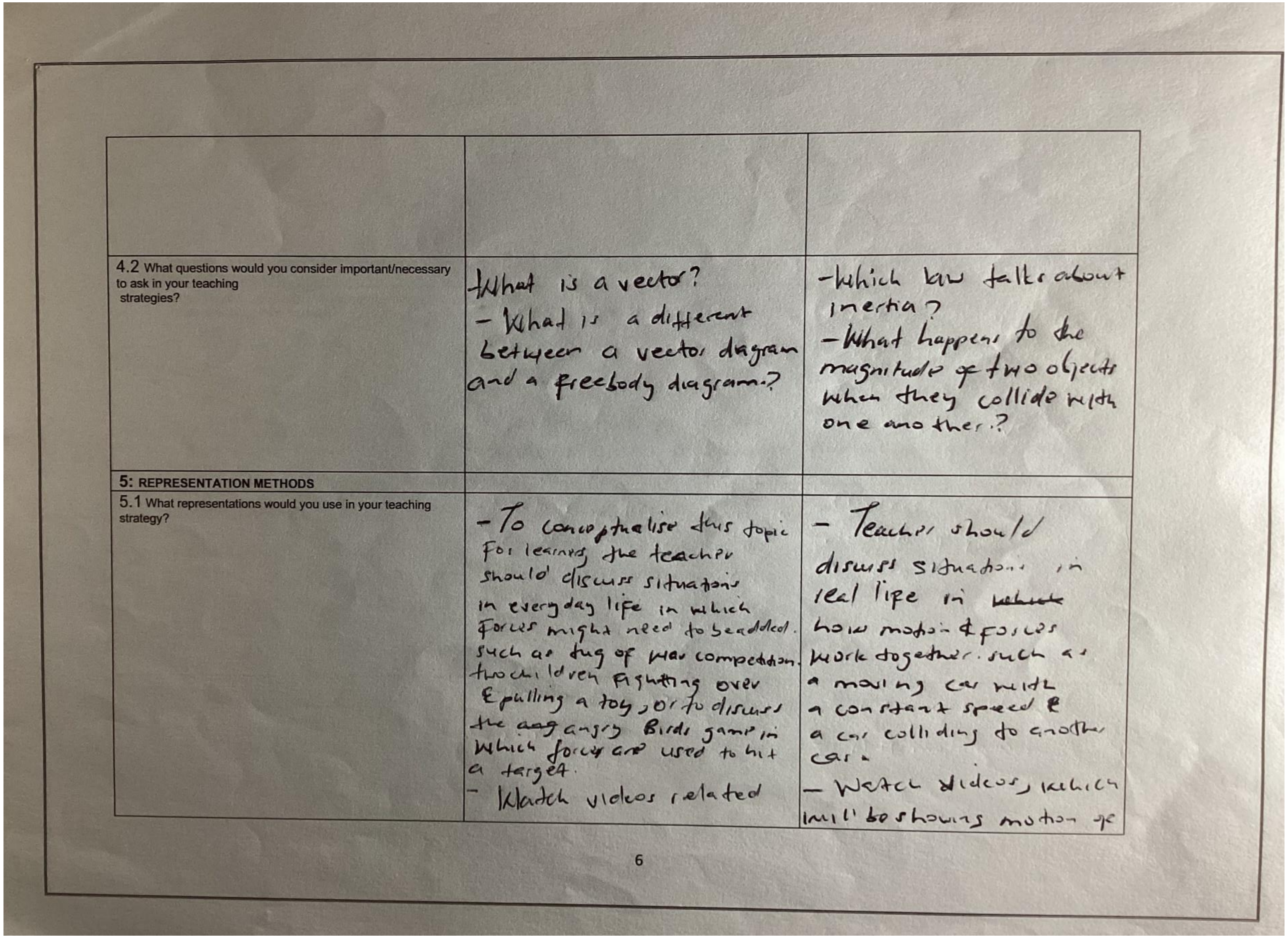

4.2 What questions would you consider important/necessary to ask in your teaching strategies?	What is a vector? - What is a different between a vector diagram and a freebody diagram?	- Which law talks about inertia? - What happens to the magnitude of two objects when they collide with one another?
5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	- To conceptualise this topic For learners, the teacher should discuss situations in everyday life in which Forces might need to be added. such as tug of war competition. two children fighting over & pulling a toy, or to discuss the ~~ang~~ angry Birds game in which forces are used to hit a target. - Watch videos related	- Teachers should discuss situations in real life in ~~which~~ how motion & forces work together. such as a moving car with a constant speed & a car colliding to another car. - Watch videos, which will be showing motion of

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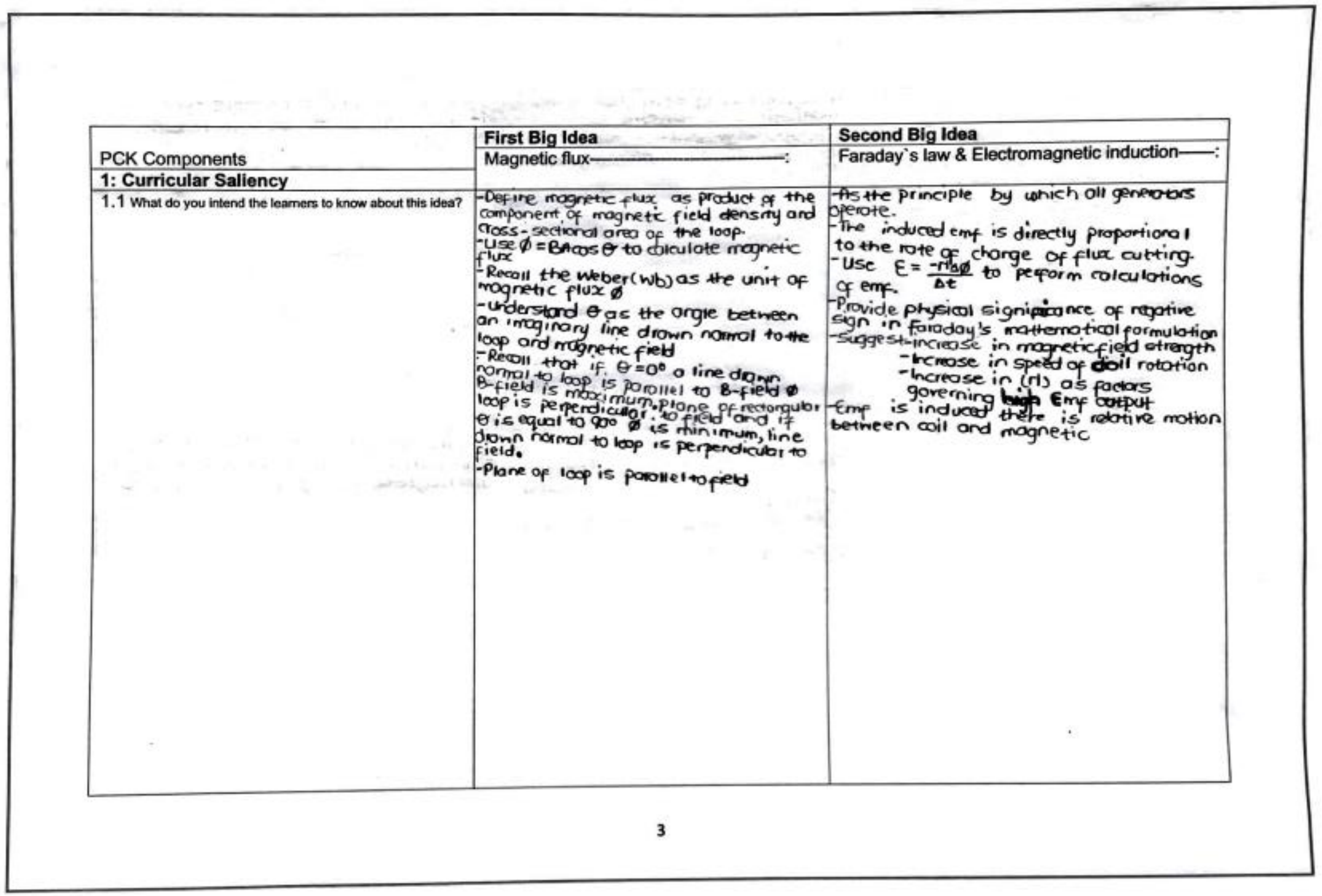
APPENDIX C1: TE1 COMPLETED POST-INTERVENTION CoRe



PCK Components	First Big Idea	Second Big Idea
	Magnetic flux——————:	Faraday`s law & Electromagnetic induction——:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	-Define magnetic flux as product of the component of magnetic field density and cross-sectional area of the loop. -Use $\phi = BA\cos\theta$ to calculate magnetic flux -Recall the weber(Wb) as the unit of magnetic flux ϕ -understand θ as the angle between an imaginary line drawn normal to the loop and magnetic field -Recall that if $\theta = 0°$ a line drawn normal to loop is parallel to B-field ϕ B-field is maximum. Plane of rectangular loop is perpendicular to field and if θ is equal to 90° ϕ is minimum, line drawn normal to loop is perpendicular to field. -Plane of loop is parallel to field	-As the principle by which all generators operate. -The induced emf is directly proportional to the rate of change of flux cutting. -Use $\mathcal{E} = \frac{-N\Delta\phi}{\Delta t}$ to perform calculations of emf. -Provide physical significance of negative sign in Faraday's mathematical formulation -Suggest -increase in magnetic field strength -Increase in speed of coil rotation -Increase in (N) as factors governing ~~high~~ Emf output -Emf is induced there is relative motion between coil and magnetic

3

1.2 Why is it important for students to know this big idea?	-Magnetic field strengths determines magnetic flux density -Faraday's formulated our mathematical understanding of magnetic flux	-Both D,C and A,C generators operation is based on electromagnetic induction principle
1.3 What concepts need to be taught before teaching this big idea?	-Magnetic field strength -Revision of the domain theory -Existence of magnetic field around coil carrying current -The right-hand rule for a straight conductor & right hand rule for a solenoid	-Definition of magnetic flux and Emf -Calculations of magnetic field strength and magnetic flux ϕ using $\phi = BA\cos\theta$

1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	-Faraday's law -Lenz's law -Application of Faraday's law in generators	-Lenz's law -D,C and A,C generators in relation to Faraday's law
2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea?	-Explaining the physical significance of θ-angle -Demonstrating the difference between magnetic field strength and magnetic flux -link between magnetic flux and flux linkage	-Relationship between non-ferromagnetic material (coil) and ferromagnetic material in generating electricity -How the force from B-field causes electron-flow if relative motion between coil & magnet is initiated -Physical significance of the negative sign Faraday's formulas
2.2 What do you consider easy about teaching this big idea?	-Explaining Φ and B by the experimental or simulation or video approach	-Demonstrating induction process by simulation, videos or experimentition

3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	-Magnetism and Domain theory -magnetic field lines and the physical significance -Right-hand for straight conduct and for solenoid	-Magnetic flux meaning -Emf meaning SI units of Ø and Emf
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	-Magnetic field lines come from the north pole and terminate at the south pole -There actuall differance between (Ø) flux and B	-Physical significance of negative sign in the mathematical formulations of Faraday's law p -Position of θ angle
4: CONCEPTUAL TEACHING STRATEGIES		
4.1 What teaching strategies would you employ to best teach this big idea?	-Experimental approach -demonstration and simulations -Explain the concepts using textbook resources -Class activities with a lot of calculations	-Explain verbally Faraday's law -Introduce lesson by linking it to magnetic flux -Define emf be 4 intro of Faraday's law -Ask questions linked to flux and field strength

4.2 What questions would you consider important/necessary to ask in your teaching strategies?	-Define magnetism -How do we represent magnetic field lines -Calculate using the equation $\phi = BA\cos\theta$ What would be the value of ϕ if $\theta = 0°$ or $0° = 90°$	-Define magnetic flux -What is the difference between magnetic flux and magnetic field -Define Emf and state Faraday's law ~~or magnet that~~. -for emf to be induced, is it coil or magnet that must move -Calculate using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ -What is the meaning of negative sign -How can emf signal be increased
5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	-Experimental demonstrations -Drawing simplified diagrams and writing notes on the chalkboard -Simulation of magnetic flux and magnetic field strength -Simulation of right hand rule	-Explain using notes on chalkboard, the statement of Faraday's law -Use of textbook question and past papers to perform calculations to questions -Ask questions like → Define - magnetic flux - magnetic field strength during introduction -Demonstrate induction using experiments simulations and videos

OTHER QUESTIONS NOT NECESSARILY LINKED TO SPECIFIC COMPONENTS		
(a) What ways would you use to assess learners' understanding of the big idea?	-Classwork -Homework on a worksheet with various quotions -Past exam papers	-Classwork and homework on a prepared worksheet - Past exampractise questions - Past test based on electromagnetism
(b) What aspects of teaching and lesson planning would you like to reflect on?	-Reflection should be centred more on magnetic flux and associated calculation	Reflection should be centred more on faraday's law and calculations and applications

APPENDIX C2: TE2 COMPLETED POST-INTERVENTION CoRe

TE 2

PCK Components	First Big Idea	Second Big Idea
1: Curricular Saliency	Magnetic flux---------------------------------:	Faraday`s law & Electromagnetic induction------:
1.1 What do you intend the learners to know about this idea?	*Define magnetic flux and magnetic field strength *Provide the difference between flux and field strength *State physical significance of the angle θ in flux equation *Calculate magnetic flux and flux change using equation $\phi = BA\cos\theta$ *Outline the parameters needed to increase the amount of flux *Present graphical relationships between ϕ and B; ϕ and A; ϕ and θ	*State Faradays law in words *Calculate the magnitude of induced emf using $\mathcal{E} = \frac{-N\Delta\phi}{\Delta t}$ *Interprete the physical meaning of each symbol in Faraday's formula *Apply the right hand rule to predict the direction of induced current as expected by Lenz's law *~~No~~ know the importance of relative motion during electromagnetic induction *Provide factors that can affect magnitude of induced emf. *Defferentiate between flux, flux change and rate of flux change

1.2 Why is it important for students to know this big idea?	* Understanding of magnetic flux is prerequisite to electromagnetic induction * The difference between ~~rate~~ of change in flux and flux is important when dealing with electromagnetic induction	* Induction of emf depends on how magnetic flux changes with time * Faraday's law is a prerequisite concept to the understanding of how electricity is produced by generators
1.3 What concepts need to be taught before teaching this big idea?	* Magnetic effect of the coil carring current * Magnetic field around a straight and solenoid ~~ma~~ * Magnetic field pattern between opposite poles of a magnet * Magnetic field lines properties	* Physical significance of angle θ in $\phi = BA\cos\theta$ * Physical significance of ϕ and $\Delta\phi$ in $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ * Right hand rule and the physics of relative motion

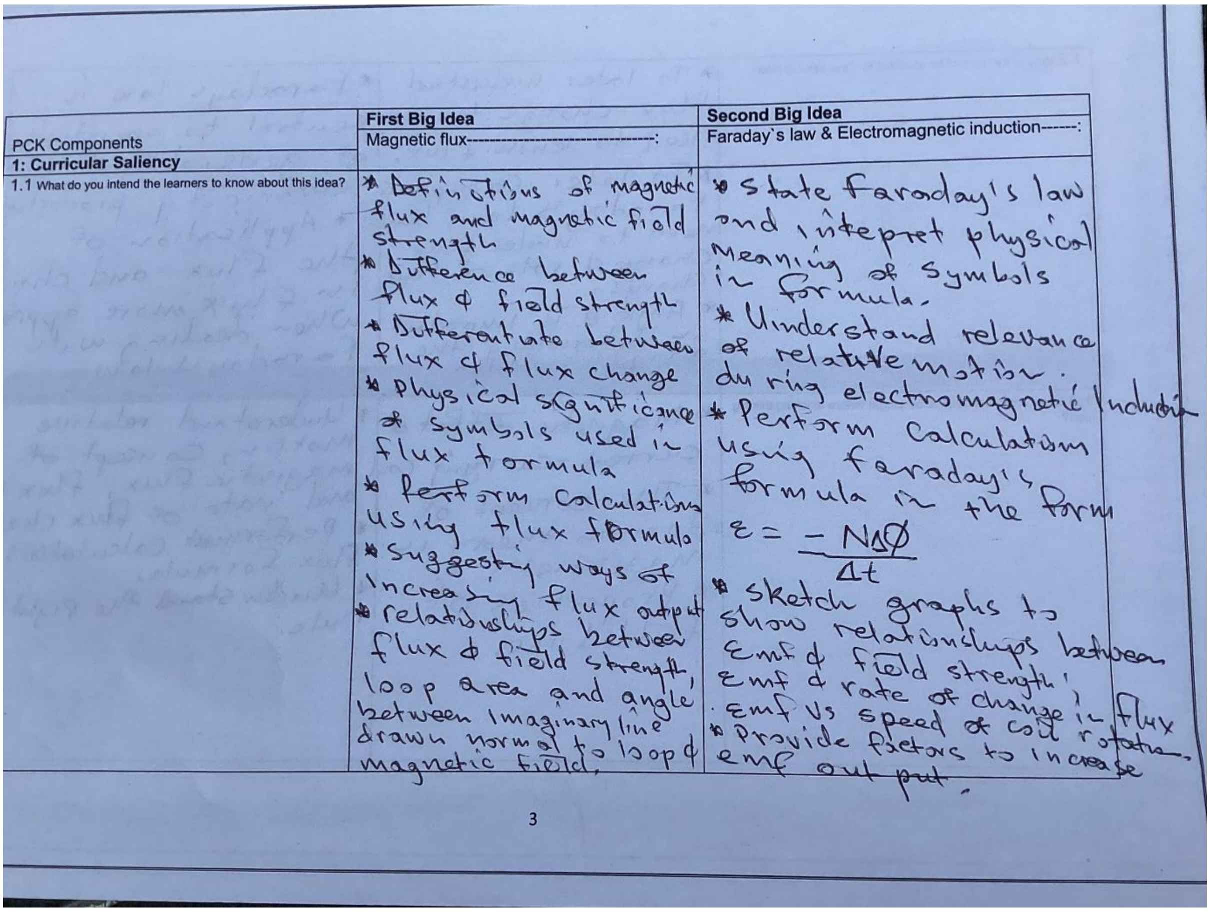
1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	* ~~Right hand rule is used in conjuction with Lenz's law~~ * The value of θ predetermines the magnitude of ϕ * Magnetude of emf depends on how $\Delta\phi$ changes with time.	* Right hand rule is used in conjuction with Lenz's law to prodict direction ~~o~~ of induced current. * All generators operate by the principle of electromagnetic induction
2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea? Some conversions needed	* Visualising the difference between flux and field strength is tricky * Calculations using $\phi = BA\cos\theta$ is not easy * Aproaching the topic experimentally is difficult	* Explenation of the physical significance of the negative sign is not easy since it's linked to Lenz's law * Performing calculations using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ might be tricky as learners might end up with a negative answer
2.2 What do you consider easy about teaching this big idea?	* By recall of definations of magnetic field strength and magnetic flux is simple and straight forward * Recalling and presenting relationships between ϕ and B, ϕ and A, ϕ and θ is easier.	* Stating Faraday's law in words and presenting factors affecting the magnitude of induced emf is easy * Demonstrating Faraday's law experimental is easy.

3: LEARNERS PRIOR KNOWLEDGE 3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	*Properties of magnetic field lines and magnetic field pattern around magnets *Laws of magnetism e.g Like poles repel and unlike poles attract*	* Right hand rule; * Magnetic flux ϕ; $\Delta\phi$ and physical significance of angle θ * Relative motion during electromagnetic induction *
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	* Learners take magnetic flux and magnetic ~~te~~ field strength to mean one and the same thing	* Learners consider right hand rule to be only applicable to current carrying conductors * Emf is induced only if it's magnet moving into coil * Induced emf is negative
4: CONCEPTUAL TEACHING STRATEGIES 4.1 What teaching strategies would you employ to best teach this big idea?	*Worksheets and chalkboard notes based on definations of flux and magnetic field strength * Simple demostration to illustrate the ~~d~~ifference between flux and field strength *Individual calkulation activities using $\phi = BA\cos\theta$	*Vebal explanations of Faradays law and Lenz's law aided with chalk board diagrams. * Simulations to explain electromagnetic induction and factors affecting emf output *Individual activities based on calculations using Faraday's formula

4.2 What questions would you consider important/necessary to ask in your teaching strategies? • Calculate magnetic flux or perform calculations using $\phi = BA\cos\theta$	* Define magnetic field strength and magnetic flux * Suggest the difference between magnetic flux and magnetic field strength * What is the relationship between ϕ and B; ϕ and A; ϕ and θ	* State Faraday's law in words * Use Faraday's law to perform calculations * Explain how direction of current can be determined * Describe how Faraday's law can be verified experimentally
5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	* Chalkboard diagrams aided with explanation notes * Simple demostration experiment	* Chalkboard diagrams aided with explanation notes. * Simulation experiments to demonstrate ~~etc~~ electromagnetic induction

OTHER QUESTIONS NOT NECESSARILY LINKED TO SPECIFIC COMPONENTS		
(a) What ways would you use to assess learners' understanding of the big idea?	* Classwork using textbooks and work sheet * End of topic test	* Classwork using texbooks and work sheet * End of topic test
(b) What aspects of teaching and lesson planning would you like to reflect on?	* Correct use of $\phi = BA \cos\theta$ * Proper understanding of difference between flux and field strength	* Proper understanding of application of right hand rule to predict direction of induced current. * Correct approach in using $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$

APPEMDIX C3: TE3 COMPLETED POST-INTERVENTION CoRe



PCK Components	First Big Idea	Second Big Idea
	Magnetic flux---------------------------------:	Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	* Definitions of magnetic flux and magnetic field strength * Difference between flux & field strength * Differentiate between flux & flux change * Physical significance of symbols used in flux formula * Perform Calculations using flux formula * Suggesting ways of increasing flux output * relationships between flux & field strength, loop area and angle between imaginary line drawn normal to loop & magnetic field,	* State Faraday's law and intepret physical Meaning of Symbols in formula. * Understand relevance of relative motion during electromagnetic Induction * Perform Calculations using faraday's formula in the form $\varepsilon = \frac{-N\Delta\emptyset}{\Delta t}$ * Sketch graphs to show relationships between emf & field strength, emf & rate of change in flux, emf vs speed of coil rotation. * Provide factors to increase emf out put.

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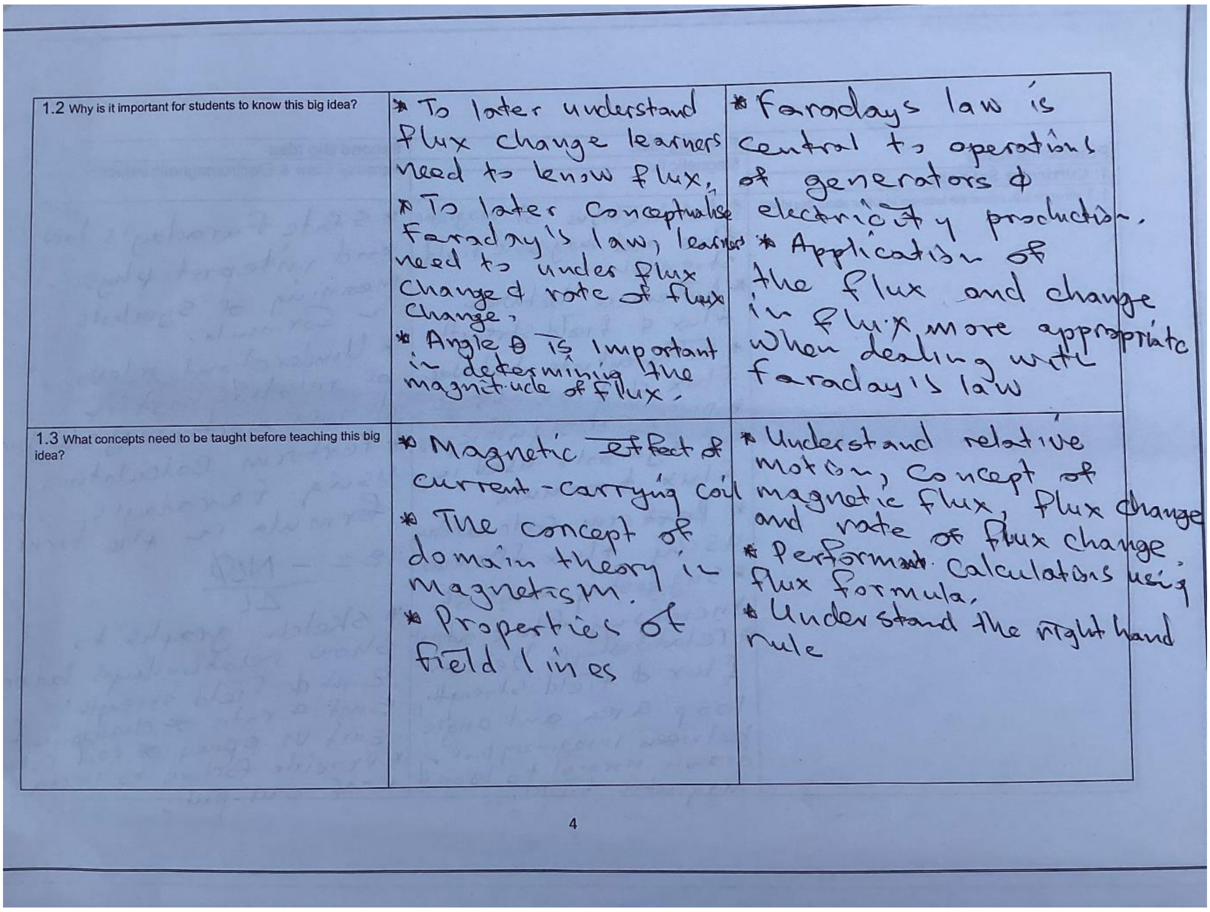
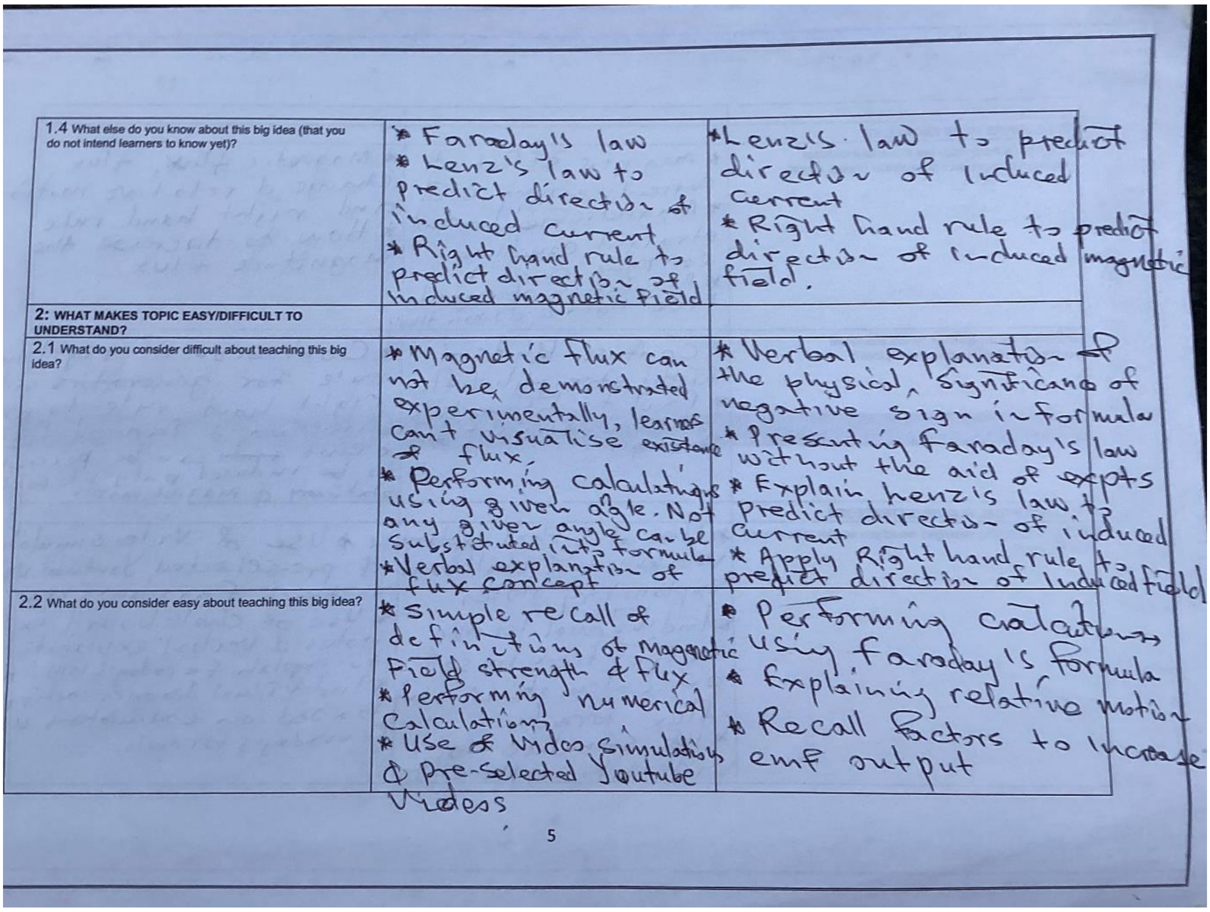
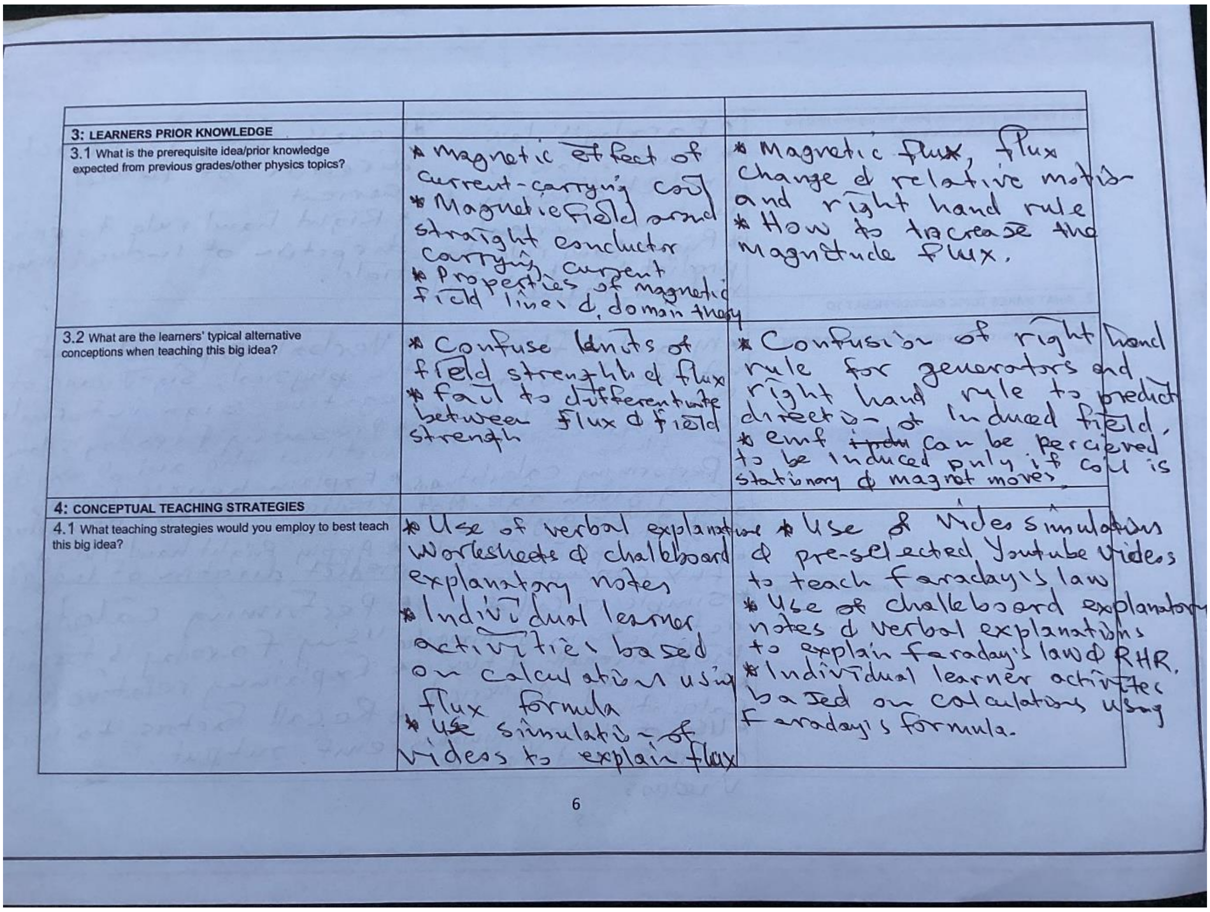


1.2 Why is it important for students to know this big idea?	* To later understand flux change learners need to know flux, * To later conceptualise Faraday's law, learners need to under flux change & rate of flux change, * Angle θ is important in determining the magnitude of flux.	* Faradays law is central to operations of generators & electricity production. * Application of the flux and change in flux more appropriate when dealing with faraday's law
1.3 What concepts need to be taught before teaching this big idea?	* Magnetic effect of current-carrying coil * The concept of domain theory in magnetism. * Properties of field lines	* Understand relative motion, concept of magnetic flux, flux change and rate of flux change. * Perform calculations using flux formula. * Understand the right hand rule



1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	* Faraday's law * Lenz's law to predict direction of induced current * Right hand rule to predict direction of induced magnetic field	* Lenz's law to predict direction of induced current * Right hand rule to predict direction of induced magnetic field.
2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea?	* Magnetic flux can not be demonstrated experimentally, learners can't visualise existence of flux, * Performing calculations using given angle. Not any given angle can be substituted into formula * Verbal explanation of flux concept	* Verbal explanation of the physical significance of negative sign in formula * Presenting Faraday's law without the aid of expts * Explain Lenz's law to predict direction of induced current * Apply Right hand rule to predict direction of induced field
2.2 What do you consider easy about teaching this big idea?	* Simple recall of definitions of magnetic field strength & flux * Performing numerical calculations * Use of video simulations & pre-selected Youtube videos	* Performing calculations using faraday's formula * Explaining relative motion * Recall factors to increase emf output



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	* Magnetic effect of current-carrying coil * Magnetic field around straight conductor carrying current * Properties of magnetic field lines & domain theory	* Magnetic flux, flux change & relative motion and right hand rule * How to increase the magnitude flux.
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	* Confuse units of field strength & flux * fail to differentiate between flux & field strength	* Confusion of right hand rule for generators and right hand rule to predict direction of induced field. * emf ~~indu~~ can be percieved to be induced only if coil is stationary & magnet moves.
4: CONCEPTUAL TEACHING STRATEGIES		
4.1 What teaching strategies would you employ to best teach this big idea?	* Use of verbal explanations Worksheets & chalkboard explanatory notes * Individual learner activities based on calculation using flux formula * Use simulation of videos to explain flux	* Use of video simulations & pre-selected Youtube videos to teach Faraday's law * Use of chalkboard explanatory notes & verbal explanations to explain Faraday's law & RHR. * Individual learner activities based on calculations using Faraday's formula.

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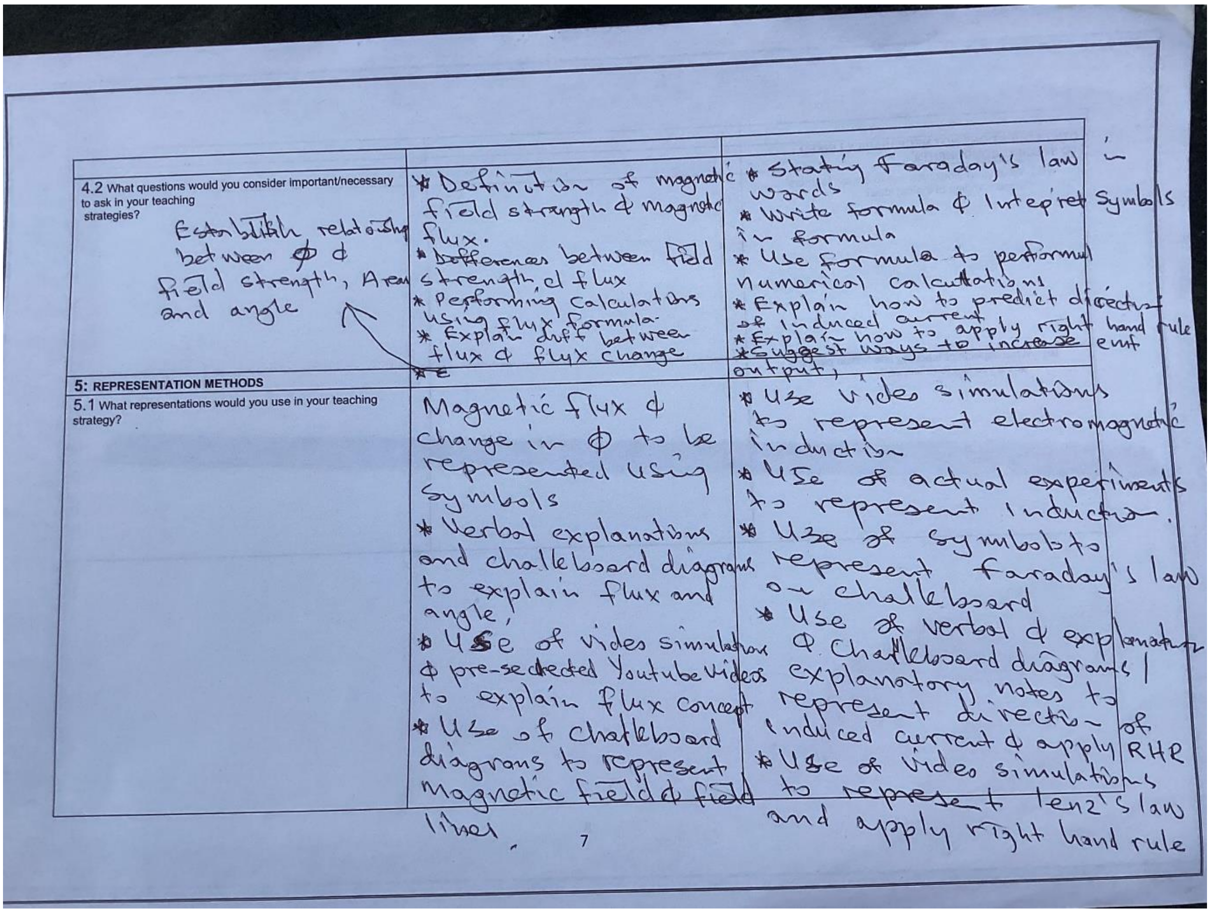

4.2 What questions would you consider important/necessary to ask in your teaching strategies? Establish relationship between Φ & field strength, Area and angle	* Definition of magnetic field strength & magnetic flux. * Differences between field strength, & flux * Performing calculations using flux formula. * Explain diff between flux & flux change	* Stating Faraday's law in words * Write formula & Interpret Symbols in formula * Use formula to perform numerical calculations * Explain how to predict direction of induced current * Explain how to apply right hand rule * Suggest ways to increase emf
5: REPRESENTATION METHODS	* E	output,
5.1 What representations would you use in your teaching strategy?	Magnetic flux & change in Φ to be represented using symbols * Verbal explanations and chalkboard diagrams to explain flux and angle, * Use of video simulation & pre-selected Youtube videos to explain flux concept * Use of chalkboard diagrams to represent magnetic field & field lines.	* Use video simulations to represent electromagnetic induction * Use of actual experiments to represent induction. * Use of symbols to represent Faraday's law on chalkboard * Use of verbal & explanatory & chalkboard diagrams / explanatory notes to represent direction of induced current & apply RHR * Use of video simulations to represent Lenz's law and apply right hand rule

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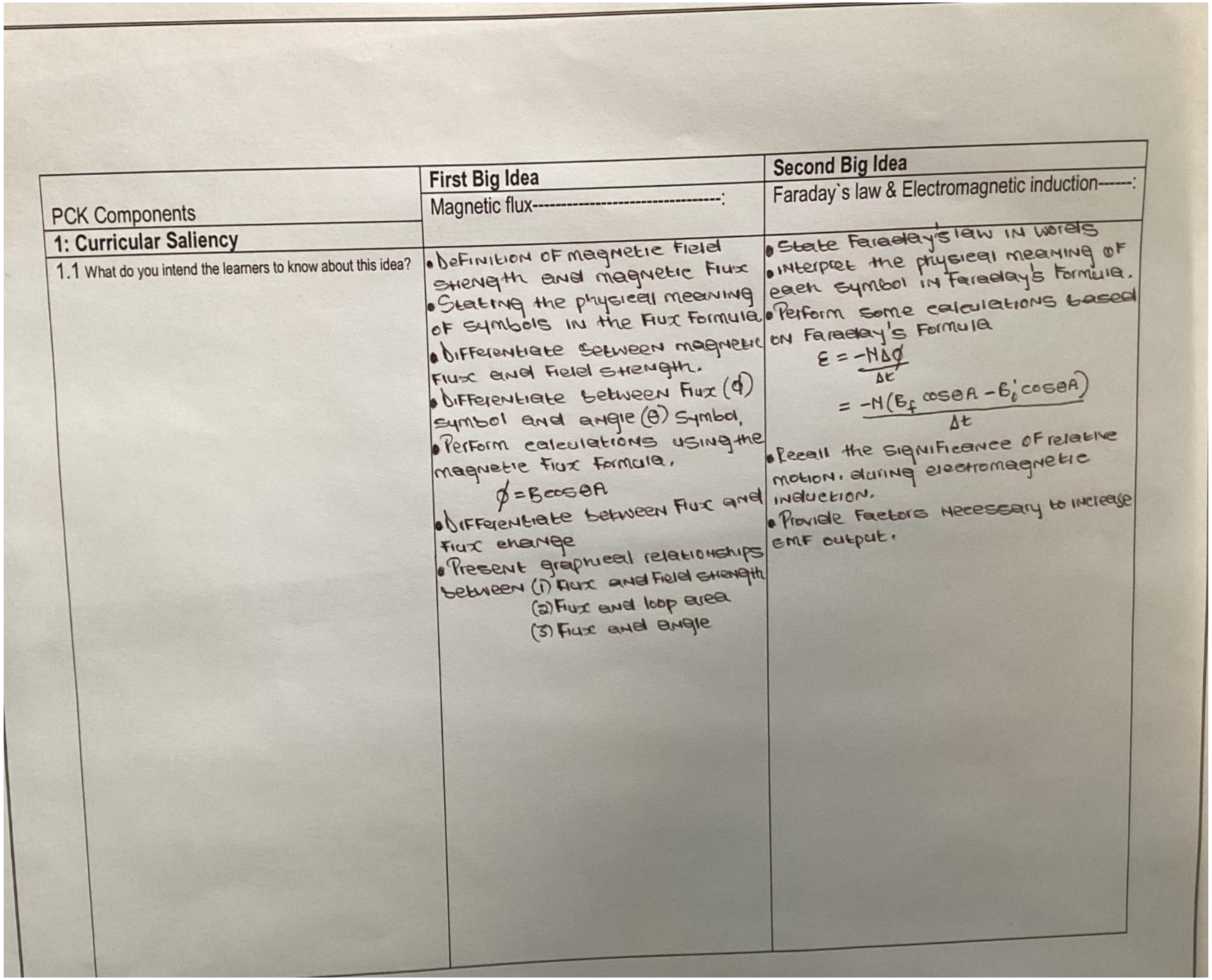
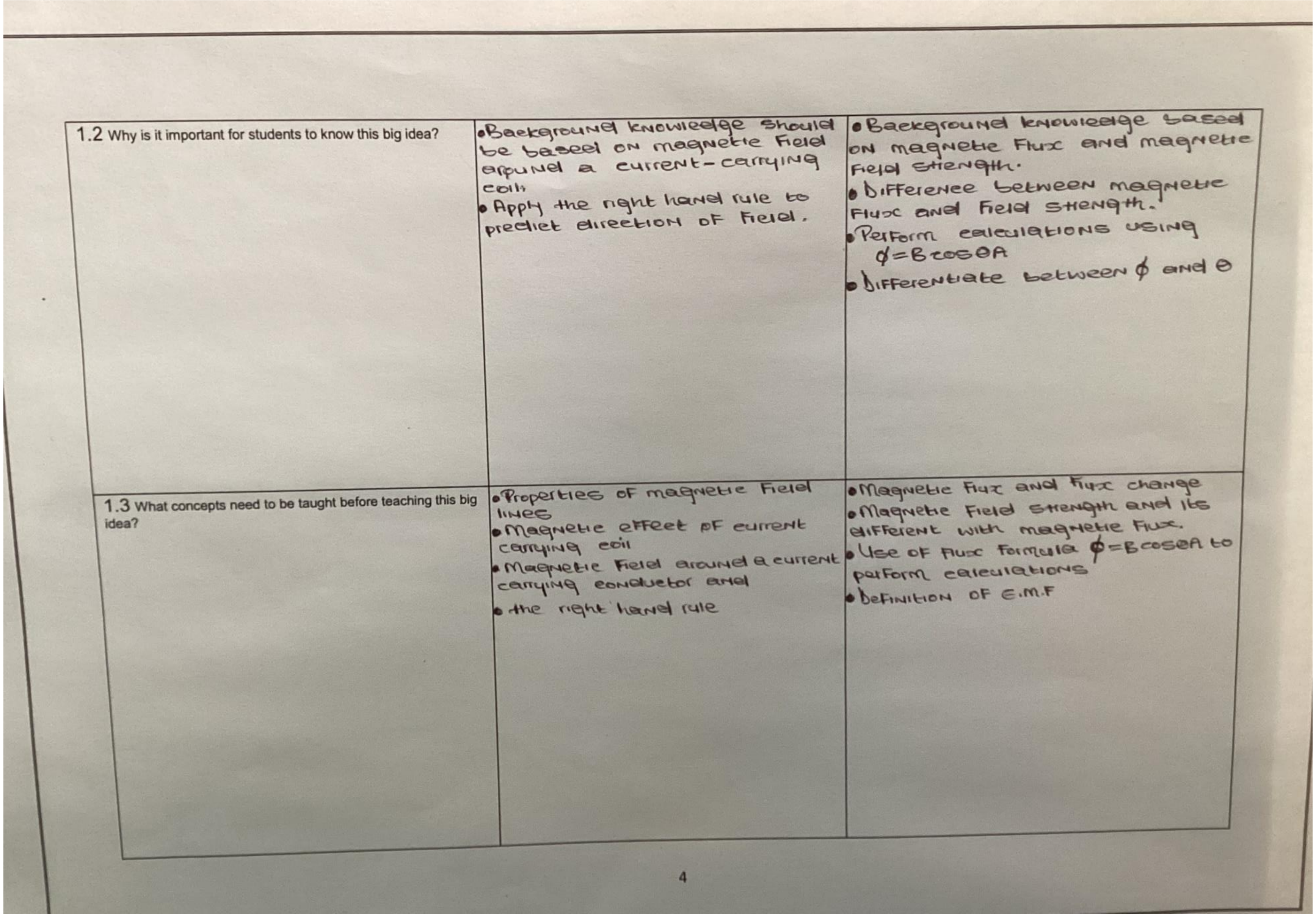
APPENDIX C4: TE4 COMPLETED POST-INTERVENTION CoRe

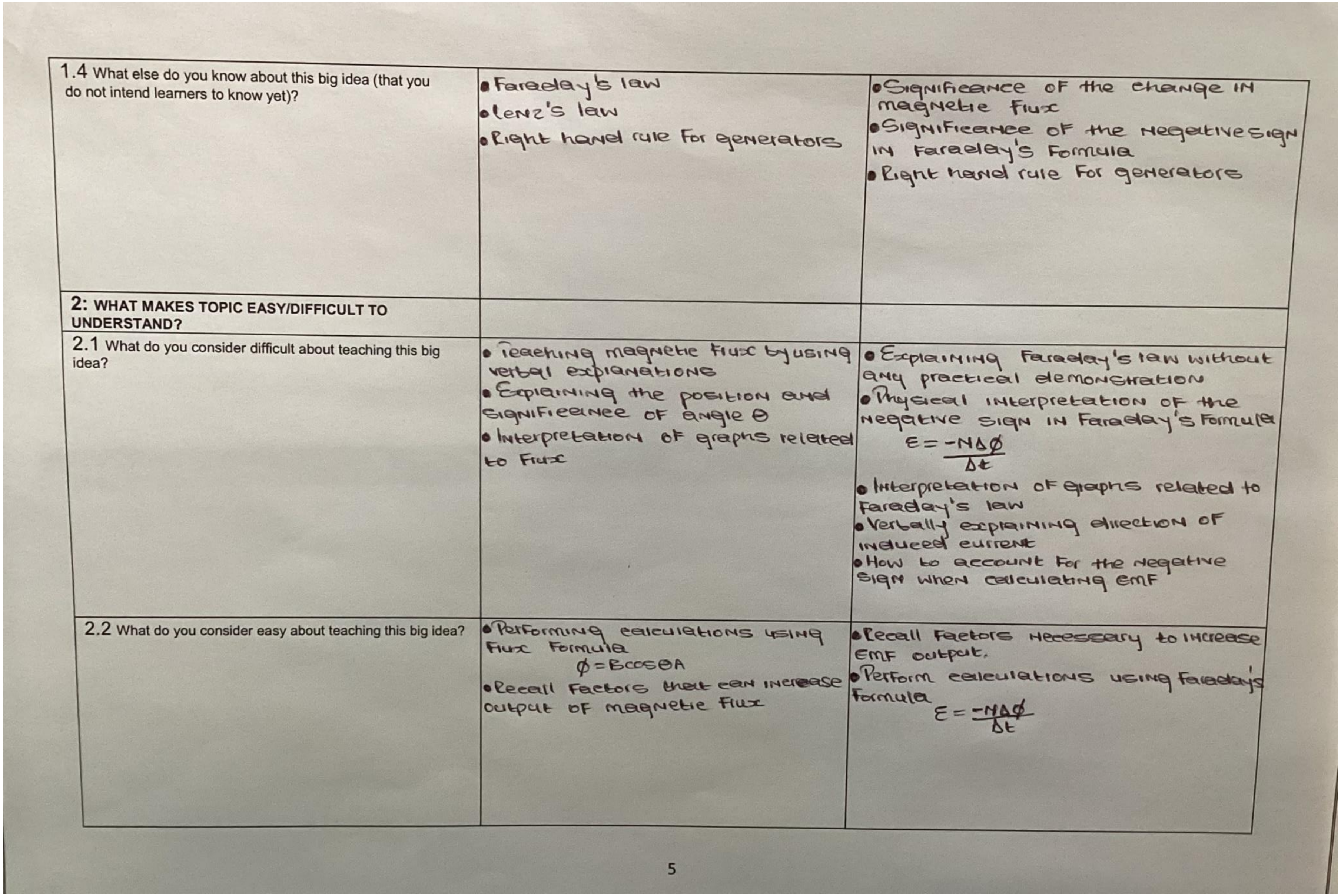


PCK Components	First Big Idea Magnetic flux-----------------------------------:	Second Big Idea Faraday`s law & Electromagnetic induction------:
1: Curricular Saliency		
1.1 What do you intend the learners to know about this idea?	• Definition of magnetic field strength and magnetic flux • Stating the physical meaning of symbols in the flux formula • Differentiate between magnetic flux and field strength. • Differentiate between flux (ϕ) symbol and angle (θ) symbol. • Perform calculations using the magnetic flux formula. $\phi = B\cos\theta A$ • Differentiate between flux and flux change • Present graphical relationships between (1) flux and field strength (2) Flux and loop area (3) Flux and angle	• State Faraday's law in words • Interpret the physical meaning of each symbol in Faraday's formula. • Perform some calculations based on Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ $= \frac{-N(B_f\cos\theta A - B_i\cos\theta A)}{\Delta t}$ • Recall the significance of relative motion. during electromagnetic induction. • Provide factors necessary to increase emf output.

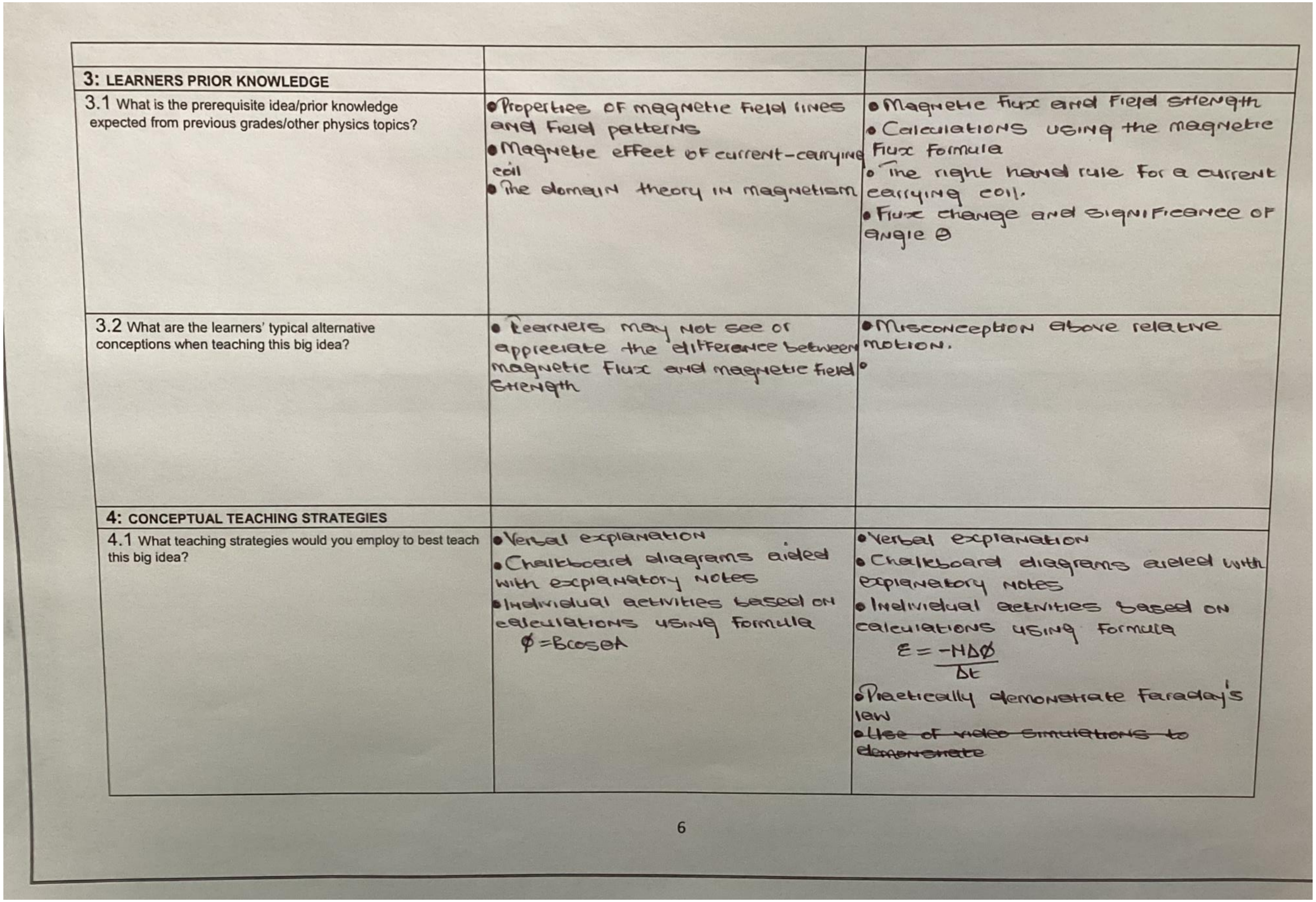


1.2 Why is it important for students to know this big idea?	• Background knowledge should be based on magnetic field around a current-carrying coil; • Apply the right hand rule to predict direction of field.	• Background knowledge based on magnetic flux and magnetic field strength. • Difference between magnetic flux and field strength. • Perform calculations using $\phi=B\cos\theta A$ • Differentiate between ϕ and θ
1.3 What concepts need to be taught before teaching this big idea?	• Properties of magnetic field lines • Magnetic effect of current carrying coil • Magnetic field around a current carrying conductor and • the right hand rule	• Magnetic flux and flux change • Magnetic field strength and its different with magnetic flux. • Use of flux formula $\phi=B\cos\theta A$ to perform calculations • Definition of E.M.F

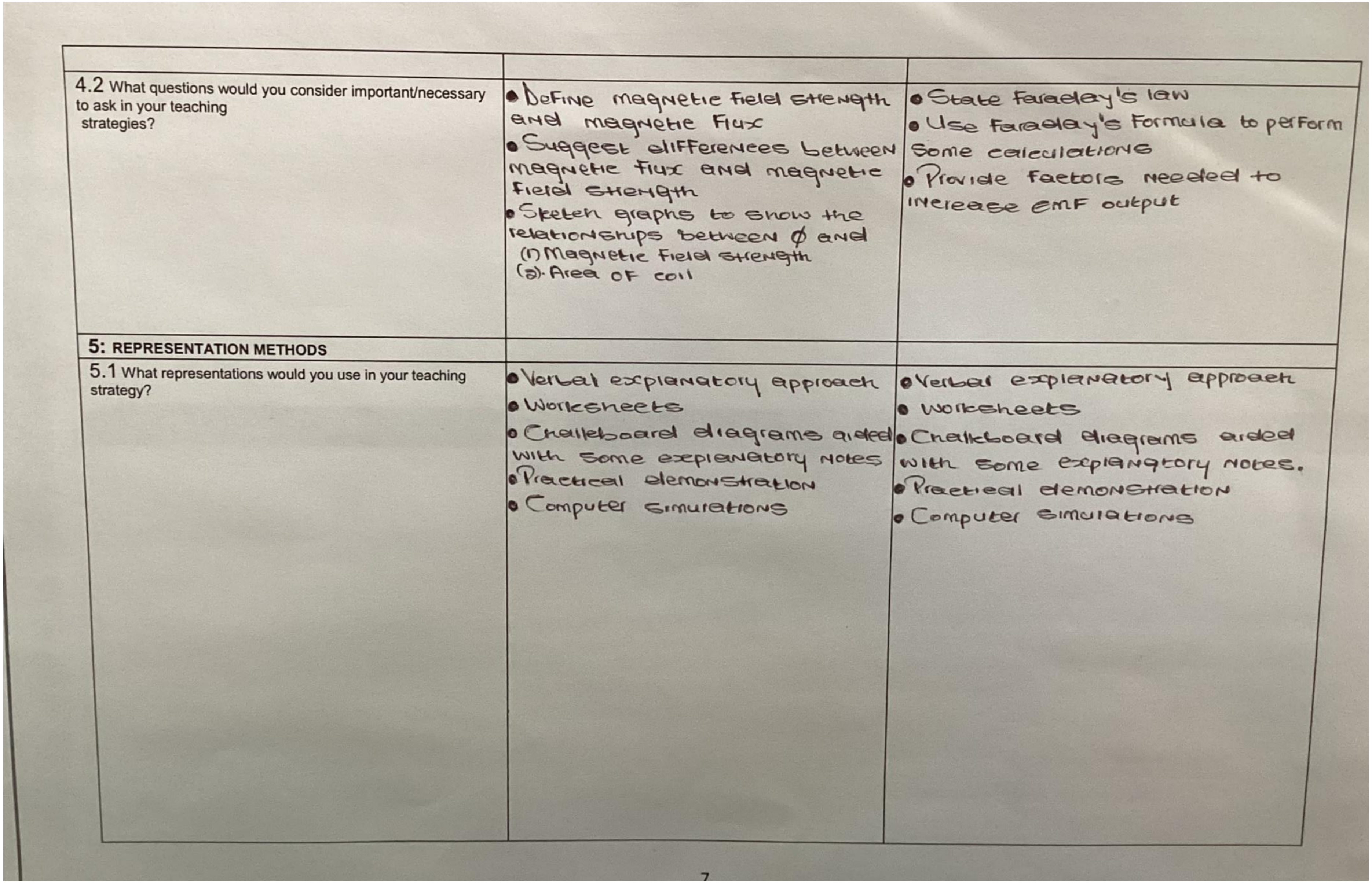
4



1.4 What else do you know about this big idea (that you do not intend learners to know yet)?	• Faraday's law • Lenz's law • Right hand rule for generators	• Significance of the change in magnetic flux • Significance of the negative sign in Faraday's formula • Right hand rule for generators
2: WHAT MAKES TOPIC EASY/DIFFICULT TO UNDERSTAND?		
2.1 What do you consider difficult about teaching this big idea?	• Teaching magnetic flux by using verbal explanations • Explaining the position and significance of angle θ • Interpretation of graphs related to flux	• Explaining Faraday's law without any practical demonstration • Physical interpretation of the negative sign in Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ • Interpretation of graphs related to Faraday's law • Verbally explaining direction of induced current • How to account for the negative sign when calculating emf
2.2 What do you consider easy about teaching this big idea?	• Performing calculations using flux formula $\phi = B\cos\theta A$ • Recall factors that can increase output of magnetic flux	• Recall factors necessary to increase emf output. • Perform calculations using Faraday's formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$



3: LEARNERS PRIOR KNOWLEDGE		
3.1 What is the prerequisite idea/prior knowledge expected from previous grades/other physics topics?	• Properties of magnetic field lines and field patterns • Magnetic effect of current-carrying coil • The domain theory in magnetism	• Magnetic flux and field strength • Calculations using the magnetic flux formula • The right hand rule for a current carrying coil. • Flux change and significance of angle θ
3.2 What are the learners' typical alternative conceptions when teaching this big idea?	• Learners may not see or appreciate the difference between magnetic flux and magnetic field strength	• Misconception above relative motion.
4: CONCEPTUAL TEACHING STRATEGIES		
4.1 What teaching strategies would you employ to best teach this big idea?	• Verbal explanation • Chalkboard diagrams aided with explanatory notes • Individual activities based on calculations using formula $\phi = B\cos\theta A$	• Verbal explanation • Chalkboard diagrams aided with explanatory notes • Individual activities based on calculations using formula $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ • Practically demonstrate Faraday's law • ~~Use of video simulations to demonstrate~~



4.2 What questions would you consider important/necessary to ask in your teaching strategies?	• Define magnetic field strength and magnetic flux • Suggest differences between magnetic flux and magnetic field strength • Sketch graphs to show the relationships between ϕ and (1) Magnetic field strength (2). Area of coil	• State Faraday's law • Use Faraday's formula to perform some calculations • Provide factors needed to increase emf output
5: REPRESENTATION METHODS		
5.1 What representations would you use in your teaching strategy?	• Verbal explanatory approach • Worksheets • Chalkboard diagrams aided with some explanatory notes • Practical demonstration • Computer simulations	• Verbal explanatory approach • Worksheets • Chalkboard diagrams aided with some explanatory notes. • Practical demonstration • Computer simulations

7

APPENDIX D1: VIDEO RECORDED LESSON OBSERVATIONS: TE1`S NARRATIVE ACCOUNT

Four sections were identified from her video-recorded lesson: Teacher TE1 taught both big ideas, (ie, MF and FL) in just one lesson. The entire lesson lasted for 62 minutes and 6 seconds.

Section 1: Introduction revision of knowledge based on the previous lesson. [5 min 53 sec]

The teacher introduced the lesson by reminding the learners that around every current carrying conductor, there exists a magnetic field. The teacher also reminded learners that the direction of the magnetic field could be predicted by applying the right-hand rule. The teacher then asked learners a couple of questions related to previous section. The questions were meant to check whether all learners are at the same level before the commencement of the new section. Given below is part of the video transcription during the introductory phase of the lesson.

TE1: *Do we all still remember how we apply the right-hand rule for a straight conductor?*

Class (with a chorus responds): *"yes".*

TE1: *Okay! Okay, So, when or how do we apply right hand rule?*

The learners were about to respond in chorus form again, but the teacher quickly interjected and requested them to raise up their hands when responding. One of the learners` hand was up. Through the teacher`s acknowledgement, the learner responded.

Learner 1: *To predict the direction of the field around a coil-carrying current.*

TE1: *Very good. But how then do we apply the right-hand rule?*

Learner 2: *We imaginarily hold the current carrying conductor with our curled fingers*

of our right hand around it is representing direction of the magnetic field while the thumb on the conductor represents the direction of the prevailing current.

TE1: *That's excellent. Did we all understand what he said?*

Class (with a chorus response): *Yes*

TE1: *Okay! Okay!. What about in the case of a solenoid? How do we apply the right-hand rule when dealing with a solenoid? Anyone who still remembers, please explain to us. Yes!*

Learner 3: *We can still make use of our right-hand rule, but this time our curled fingers* *point in the direction of the prevailing current while the thumb points to the south pole of the magnetic field.*

TE1: *That's excellent. You have said it well. Yes, that's correct. In other words, in our previous lesson, we said that generally every coil carrying current, there exist a magnetic field. Electric current gives rise to the magnetic effect. Earlier scientists discovered and appreciated that electrical current results in a magnetic field. Is there anyone with a question based on what we have covered so far in this section?*

The teacher`s introduction was merely based on reflecting on what was covered in the previous lesson. At this stage no learner asked a question.

Teacher TE1 then distributed some worksheets to all the learners in her class. She then went on to write a few notes on the chalkboard based on concept of electromagnetic induction (EMI). Meanwhile, her learners captured the notes into their notebooks. She then turned and faced her learners to introduce the EMI section. She stated off by narrating to her learners the scientific history of Michael Faraday and how he arrived at the concept of electromagnetic induction. All her learners listened attentively and curiously to the story. The following is part of a transcription from the video recordings about how the teacher introduced the concept of electromagnetic induction to her grade 11 learners.

TE1: *According to Faraday, he argued and thought for himself that if electricity can result in a magnetic field, then a magnetic field must in one way, or another be able to generate electricity. This phenomenon which Faraday later called electromagnetic induction took some couple of years for him to prove it to the scientific global community. The discovery of EMI has made it possible for us to generate electricity. Faraday was a great scientist, isn't it? So, EMI is the phenomenon where emf plus current signal is induced in a conductor if magnetic flux is altered. This can easily be established by moving a permanent bar magnet and coil of copper wire connected to a galvanometer. No power supply is needed here. It's quite magical, isn't it?*

Then suddenly there is some mummering and whispering in class and learners turning towards each other prompting the teacher to ask them.

TE1: *Hey, shhhhh!. What is the problem? Or is there anything wrong with my explanations? Or is there anyone with anything to say? If you want to ask something, please raise up your hand*.

Then another learner raises up his hand.

Learner 4: *Excuse me Ma'am, what are you referring to as EMI?*

TE1: *Oh!, sorry. I got carried away and forgot to tell you. Thanks very much for asking.*

Okay, EMI is an acronym or short for electromagnetic induction.

The teacher went to the chalkboard and wrote **E**lectro**M**agnetic **I**nduction (EMI). Teacher also presented some few chalkboard notes to the learners based on electromagnetic induction. Teacher shown in figure 5 then provided a brief explanation to paraphrase her notes based on EMI with the aid of worksheet.

Figure 5: Teacher introducing EMI to learners.

She then assured her learners that she was going to demonstrate the concept of EMI during the same lesson. Another learner raises up hand to ask a question.

Learner 5: *I heard you mention something like magnetic flusk or flux. What is that?*

TE1: *Ohhh! magnetic flux, don't worry, that is exactly what we are going to focus on just now.*

<u>Section 2</u>: Teaching the first big idea of MF followed by a short classwork assessment [16 min 13 sec]

Teacher goes to the chalkboard and writes the definition of magnetic flux

TE1: *Now, we want to discuss about magnetic flux before we finally present faraday`s law of EMI. Magnetic flux is a product of the component of magnetic field strength and cross-sectional area of the loop. I hope you still remember components of vectors, a section which we treated earlier this year. Even a magnetic field is also a vector field.*

Now, mathematically magnetic flux can be expressed using that equation on page 9 of the hand-out. Let me also present the equation to you on the chalkboard.

The teacher then wrote the magnetic flux equation on the chalkboard as $\varnothing = B\cos\theta A$.

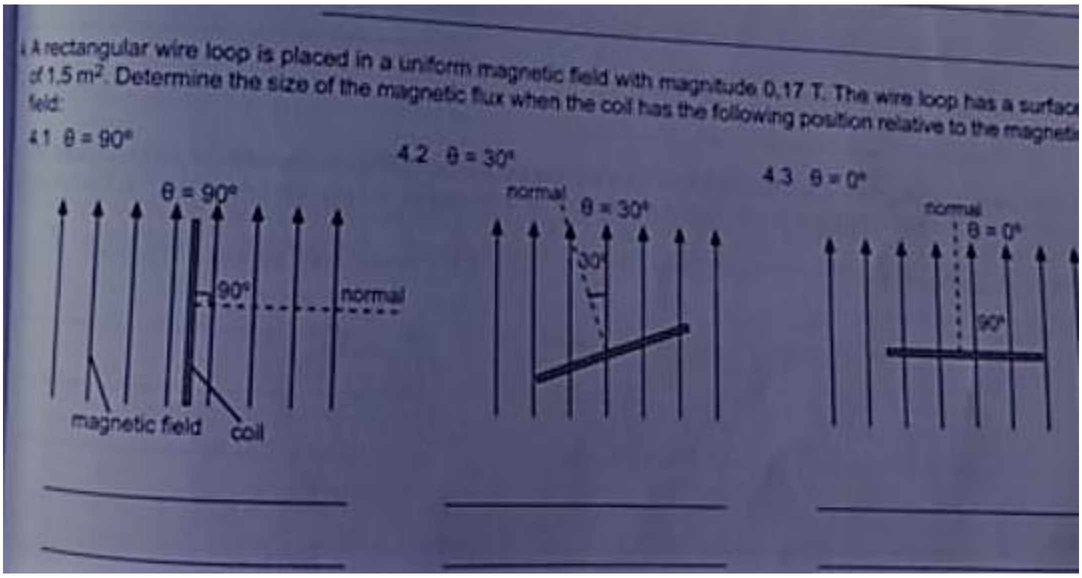
Learner 2: *Is that a “theta” or what?*

TE1: *No, it’s not theta (θ), $\varnothing$ is called “fi” and it`s also derived from the Greek alphabet just like θ and other symbols that we use in mathematics. Is that clear?*

Teacher continues to explain to the learners about magnetic flux and how to perform calculations using the formula which she had written on the chalkboard.

TE1*: Magnetic flux in other words simply brings into imaginary perspective, the flow of field lines or field flow. Magnetic flux is measured in webers (Wb). In the mathematical statement of magnetic flux, B represents magnetic field strength measured in tesla (T) and, mean almost the same as magnetic flux. A represents cross-sectional area of the loop measured in square meters (m^2); and θ represents the angle between an imaginary line drawn normal to the loop and magnetic field. Remember in physics that normal means perpendicular or 90^o.*

Teacher then goes on to lead the class in performing some numerical calculations of magnetic flux on the chalkboard while again picking from questions in in the worksheets provided to learners. Teacher then discusses with learners the solutions to some of the questions in the worksheet. Teacher then instructs learners to quickly attempt the other questions 4.1; 4.2 and 4.3 in their classwork books (see figure 6). Learners start working on the given task while teacher moves around monitoring progress and responding to individual questions.



A rectangular wire loop is placed in a uniform magnetic field with magnitude 0,17 T. The wire loop has a surfac
of 1,5 m^2. Determine the size of the magnetic flux when the coil has the following position relative to the magneti
field:

4.1 $\theta = 90°$

4.2 $\theta = 30°$

4.3 $\theta = 0°$

Figure 6: Snapshot of question from learners` worksheet based on magnetic flux

TE1: *Alright! I hope everyone has managed to answer the questions*.

One learner raises up his hand to ask. The learner`s question is based on the activity which they were given by their teacher.

Learner 4: *Is it possible to get zero as an answer for ∅? If so, what is the physical meaning of a zero answer.*

TE1: *That's a good question. Who can try and suggest an answer to that question?*

Learner 3: *I think it's because when ∅ is zero, θ is 90, cos90=0, and physically an imaginary line drawn normal to the loop is perpendicular to the magnetic field while plane of loop is parallel to the magnetic field.*

TE1: *Well said, that's a very good explanation. I hope we are all satisfied with the answer. Okay, now please quickly finish up the activity.*

Teacher gives learners some few minutes to allow them to finish up writing the task before introducing Faraday`s law to the learners.

Section 3: Teaching the second big idea based on Faraday's law and EMI followed by a short practice exercise [34 min 48 sec]

TE1: *Now let us finalise our lesson by discussing about Faraday's law of electromagnetic induction.*

Teacher writes Faraday`s law statement on the chalkboard as follows.

"Whenever there is a change in the magnetic flux due to a coil of wire connected in a

circuit, an emf is induced in the coil causing current flow in the coil. The induced emf is directly proportional to the rate of change in magnetic flux cutting."

TE1: *Right, this is the statement of Faraday`s law. Okay. In other words, the law is in two parts. The first part focuses on relative motion between the coil and magnet. Meaning that emf can only be induced if there is relative movement between the coil which of course will be a non-ferromagnetic metal and a magnet. The second part also emphasises on magnitude of emf which depends on factors such as speed at which the motion of magnet is executed, magnetic field strength and number of coil turns.*

Teacher writes the mathematical statement of the law on the chalkboard and explains the physical meaning of the symbols used.

$$\varepsilon = \frac{-\mathrm{N}\Delta\varnothing}{\Delta t} \qquad \text{where } \varnothing = \mathrm{B}\cos\theta\mathrm{A}$$

She then went further to explain the physical meaning for each of the symbols by also writing them on the board.

TE1: *$\mathcal{E}$ stands for emf or electromotive force measured in volts, the capital N stands for number of coil turns, Δt stands for change in time expressed in seconds, $\Delta\varnothing$ stands for change in magnetic flux. Please note that there is a negative sign in the formula. So, every time when we perform a calculation don't forget to include the negative sign if you don't want to get a wrong answer. I think you can also see the presents of magnetic flux $\varnothing$ in Faraday`s formula. It is the same $\varnothing$ which we have just been dealing with in our previous activity.*

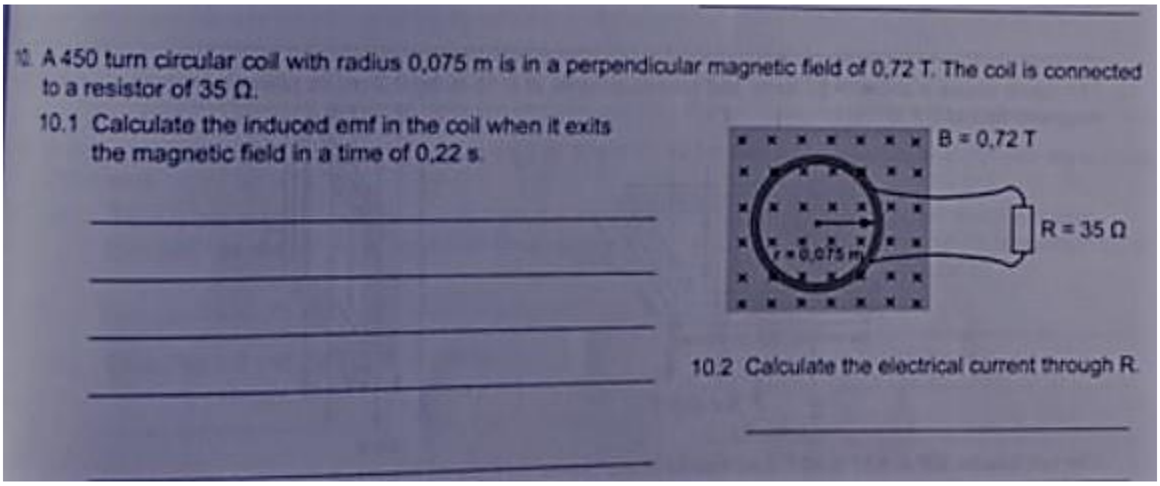
One learner raises hand.

Learner 4: *What is the physical significance of the negative sign in Faraday`s formula?*

However, the teacher did not provide a convincing answer to the learner. She instead quickly brushed the question and said that the response was not part of CAPS syllabus.

TE1: *That's a very good question my boy. But for now, don't bother yourself about the physical significance of the negative sign. The negative sign has to do with something associated with what we call Lenz`s law and it's not in your syllabus. We cannot waste our time on something that will never be examined. But if you want to know about Lenz`s law, you can come and see me later in my office. So, for now, just make sure that you include it every time you perform a calculation which has to do with Faraday`s formula. Let`s do one or two examples together based on Faraday` s law before I give you something for you to do as classwork.*

Teacher then discusses with learners the solution to one of the questions in the worksheet. She presents one of the solutions on the chalkboard. Teacher then instructs learners to quickly attempt question 10 from the worksheet (see figure 7). Learners start working on the given task while teacher moves around monitoring progress and responding to individual questions.



10 A 450 turn circular coil with radius 0,075 m is in a perpendicular magnetic field of 0,72 T. The coil is connected to a resistor of 35 Ω.

10.1 Calculate the induced emf in the coil when it exits the magnetic field in a time of 0,22 s.

10.2 Calculate the electrical current through R.

Figure 7: Snapshot of question from learners` worksheet based on EMI

Teacher then chooses to use her personal laptop in order further learners` understanding of the EMI concept via simulation videos. She then set up her laptop to demonstrate EMI and Faraday`s law to her learners in the form of a video simulation.

TE1: *Okay, can you please stop whatever you are doing. It's now time for us to demonstrate EMI. Now, EMI is the wonderful and ground-breaking idea which Faraday used to convince the world that we can get electricity from magnets. I hope everyone will be able to view, enjoy and appreciate the simulations.*

Teacher sets up the video simulations from her laptop and uses it as a teaching aid.

TE1: *Right, can we all see that? As you can see from the simulation, first we have the magnet held stationary outside the coil, then next we have magnet entering the coil. Then next we have magnet held inside the coil. And lastly. we have magnet being pulled in opposite direction. I would like us to observe the behaviour of the meter at each of those 4 different positions of the magnet. I think we all can see that there is no battery, or any form of power supply connected here. Can you see that the meter on the galvanometer reads zero when magnet is held stationary outside? Meaning that no emf is induced inside the coil of wire. Who can explain or suggest why?*

Learner 4*: When the strong permanent bar magnet was held stationary outside the coil with its north pole being the near side, there was no reading on the galvanometer.*

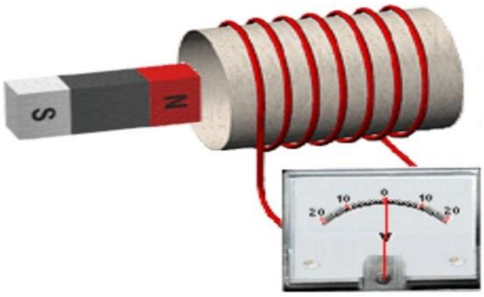


Figure 8: Screenshot of simulation showing no deflection on the galvanometer with magnet held stationary outside coil

Learner 3: *I think it is because there is no movement of the magnet into the coil.*

TE1: *Excellent, that's very correct. Keep watching. Keep watching. What can you observe when a magnet is pushed into the coil?*

Leaner 1: *When the strong magnet was then fast pushed into the coil, the*

galvanometer gave a reading by deflecting towards the left.

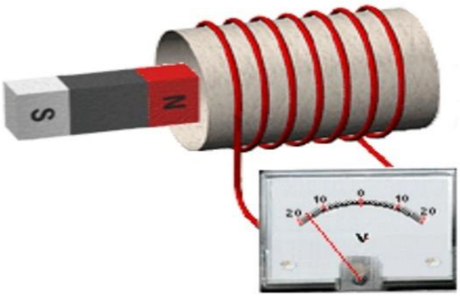


Figure 9: Screenshot of simulation showing a deflection on the galvanometer after a fast push of magnet into the coil.

Learner 6: *The pointer on the meter of the galvanometer is deflected to one side showing that an emf has been induced in the coil.*

TE1: *Very good. Can you all see that? Keep on watching. Now what about when the magnet is held stationary inside the coil, just watch this part now. what happens and why?*

Learner 3: *When the strong magnet was held stationary inside the coil there was no response from the galvanometer as it gave a zero reading.*

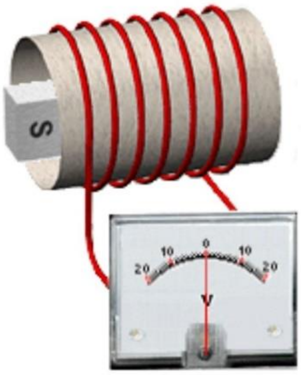


Figure 10: Screenshot of simulation showing magnet held stationary inside the coil

TE1: *Who can explain why?*

Learner 7: *The pointer of the galvanometer reads zero and no emf is induced inside the coil of wire. I think it is because there is no motion.*

TE1: *You have said it well my boy. Which means that our emf is induced only when the magnet makes a movement into or out of the coil. Now, what about when the magnet is pulled out backwards.*

Learner 4: *When the strong permanent bar magnet is fast pulled out of the coil, the galvanometer deflects to the right.*

Figure 11: Screenshot of simulation deflection on galvanometer after magnet is fast pulled out of coil

Learner 8: *The meter deflects in the opposite direction.*

TE1: *Very excellent. It's interesting, isn't it? Now watch. What about if the magnet is pushed into coil faster or pulled out of the coil faster what do you think will happen?*

Learner 1: *I think there we should observe a greater deflection of the meter.*

TE1: *I hope you all enjoyed watching the simulations related to EMI. Any questions so far?*

Section 4: Concluding the lesson [5 min 12 sec].

Teacher closes her laptop. She goes to the chalkboard and writes application of EMI and Faraday`s law. Teacher then goes further to explain the significance of Faraday`s law in everyday life.

TE1: *This section about electromagnetism and Faraday`s law in grade 11 CAPS syllabus is a pre-requisite to another section which you are going to meet next year in grade 12 called electrodynamics. The section of electrodynamics focuses on motors and generators. In other words, there is no way you can claim to fully understand generators without prior understanding of Faraday`s law. The principle or law by which generators operate is called Faraday`s law of electromagnetic induction*.

This brings us to the end of this section. If you have any questions pertaining this section, please feel free to ask. Or you can as well freely come to me as individuals if you have any challenges.

The teacher requested the learners to prepare for a test based on EMI.

TE1: *Let's see, what day is it today? Oh yeah, it's Tuesday. So, you will be writing a test based on Faraday`s law and electromagnetic induction on Monday. Please prepare yourselves for it because I am going to record your performance from that test. Your performance in that test is going to be part of the school-based assessment (SBA) marks. I would like you to do all the questions in your worksheet as part of your homework. We will go through the solutions tomorrow.*

The teacher gave learners some written tasks at the end to be done at home.

APPENDIX D2: VIDEO RECORDED LESSON OBSERVATIONS: TE2`S NARRATIVE ACCOUNT

The following is a detailed narrative account of what transpired during the lesson as captured in the video recordings of TE2`s lesson.

Section 1: Introduction revision of knowledge based on the previous lesson. [5 min 13 sec]

TE2: *In our previous lesson we discussed about the physical interactions between*

charges, currents as well as the electric and magnetic fields which arise from them. Am I right?

Class: *Yes sir*

TE2: *Who still remembers about what we discussed?*

Learner 1: *The fact that an electric current creates a magnetic field around the coil of*

wire or within the solenoid.

TE2: *That's excellent. What else? Who can add? Yes*

Learner 2: *That we can predict the direction of the field by applying the right-hand rule*

TE2: *Very correct who still remembers how we apply the right-hand rule.*

Another hand is up. The learner started to illustrate how to apply the rule while absent-mindedly using her left hand. Other classmates quickly notice it and laughs. The teacher quickly reminds her.

TE2: *Since it`s called the right-hand rule, it means we make use of the right hand in*

our illustrations.

The learner now continues with her explanations while this time illustrating with her right hand.

Learner 3: *We make use of the right-hand rule whereby if it is a straight conductor carrying current then, the thumb will point in the direction of current while the curled fingers will point the direction of the magnetic field.*

TE2: *Do you also still remember that we can experimentally demonstrate the existence of a magnetic field around a straight conductor carrying current by using a magnetic compass?*

Class: *Yessss*

TE2: *What if it's a solenoid. I mean what if current is flowing through a solenoid? Do we still apply the right-hand rule?*

Learner 4: *Yes. we still apply the right-hand rule. but however, the curled fingers will point int the direction of the current while the thumb points in the direction of the magnetic field.*

TE2: *You are very correct.*

The teachers goes further to remind learners about magnetism.

Figure 12: Screenshot of TE2 recapping Grade 10 magnetism with Grade 11 learners. Source: Researcher's own.

TE2: *In Grade 10 we discussed about magnetism. We defined magnetism as a region of space around a magnet where magnetic force is experienced. We also indicated that magnetic field lines are imaginary lines drawn around a magnet. We also said that the field lines emanate from the north pole and advance towards the south pole.*

The introductory discussion touched on recapping Grade 10 section magnetism, magnetic field strength and magnetic field patterns as depicted by figure 12.

<u>Section 2</u>: Teaching the first big idea of magnetic flux followed by a short classwork assessment [19 min 56 sec]

Teacher then goes on to introduce the new topic of magnetic flux and Faraday`s law of electromagnetic induction.

TE2: *Today`s lesson is mainly about magnetic flux and Faraday`s law of electromagnetic induction. We want to discuss and later demonstrate that a changing magnetic field can generate current flow through a coil. But before then, we need to discuss and clarify the concept of magnetic flux. There is no way we can talk about electromagnetic induction before we deal with magnetic flux.*

The teacher continues with his verbal explanation on magnetic flux while learners listen attentively.

TE2: *The take off point is magnetic flux density, which is a measure of the strength and direction of magnetic field. Magnetic field strength deals with strength of the magnetic field. It's a vector quantity. The symbol for magnetic flux density is B, and SI unit of B is the tesla which we represent with a capital T. Magnetic flux by is a product of the component of magnetic flux density perpendicular to the loop and cross-sectional area of the loop. Magnetic flux is also regarded as magnetic flux linkage. The SI unit of magnetic flux is called the weber represented by Wb.*

Teacher presents the mathematical expression of magnetic flux on the chalkboard as: $\emptyset = BCOS\theta A$

TE2: *This is the mathematical expression for magnetic flux .in this formula,* $\emptyset$ *is magnetic flux and its scientific unit is called webers and symbol for webers is Wb. The B stands for the magnetic field strength. The scientific unit of magnetic field strength is called tesla and symbol for tesla is Wb. Then,* θ *represents the angle between magnetic field and a line normal to the loop. The symbol, A represents the cross-sectional area of the loop. Any questions so far?*

The teacher further paraphrases the meaning of magnetic flux.

TE2: *In other words, magnetic flux ∅ is a measure of the total magnetic field lines passing a loop of predictable cross-sectional area. The stronger the magnetic field B passing through an area of loop A, the higher the magnitude of the magnetic flux.*

If an imaginary line drawn normal to the loop is parallel to the magnetic field while the plane of the loop is perpendicular to the magnetic field, then higher magnetic flux will be captured since more field lines will pass through the loop and angle between magnetic field and a line normal to the loop will be 0. If an imaginary line drawn normal to the loop is perpendicular to the field while the plane of the loop is parallel to the field, then no magnetic flux passes through the loop. In other words, the magnetic flux will be identically equal to zero since no field lines will pass through the loop and the angle between magnetic field and a line normal to the loop will be 90. When performing a calculation of the flux please don't just use any given angle. Remember that the angle to be used in our calculations should lie between an imaginary line drawn normal to the loop and the magnetic field. always remember that for maximum MF, θ=0, and for minimum MF =90. Any questions so far?

There is a hand raised up by a learner.

Learner 3: *What does MF stand for?*

TE2: *Anyone who can guess?*

Learner 5: *I think it stands for magnetic flux.*

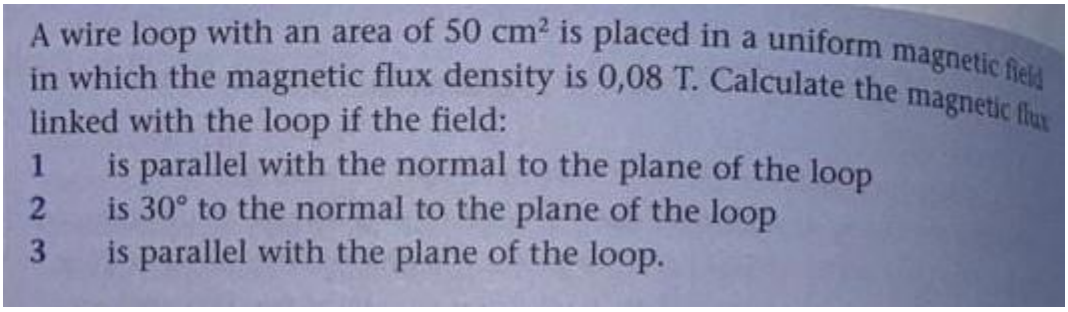
TE2: *Yes, you are right.*

The teacher then goes further to explain the change in magnetic flux.

TE2: *As the coil rotates by intercepting magnetic field lines, it means that the magnetic flux through the loop will vary. This variation in magnetic flux due to coil rotation leads to what we call magnetic flux change.*

Teacher then goes further to guide learners through an example of how to calculate magnetic flux. He then selected another problem related to magnetic flux from the worksheet for learners to attempt as individuals in their classwork exercise books.

TE2*: Now can I give you this question so that you can perform some calculations while using flux formula. Can you please try answer the questions in your classwork book as individuals. I will give very few minutes. Where you don't understand please feel free to raise up your hand so that I can come and assist you.*



A wire loop with an area of 50 cm^2 is placed in a uniform magnetic field in which the magnetic flux density is 0,08 T. Calculate the magnetic flux linked with the loop if the field:

1 is parallel with the normal to the plane of the loop
2 is 30° to the normal to the plane of the loop
3 is parallel with the plane of the loop.

Figure 4.13: Snapshot of question given to learners as a class activity.

Meanwhile, teacher moves around monitoring progress and attending to individuals with challenges. Teacher then draws the attention of all his learners to the next and last section of EMI.

<u>Section 3:</u> Teaching the second big idea based on Faraday's law of EMI using chalkboard diagrams aided by explanatory notes [18 min 12 sec]

TE2: *By now, I think, and I hope you have all finished dealing with the flux problem in your worksheet. Is there anyone who has not yet finished it?*

All learners are quiet.

TE2: *Silence means we are all through. Now let us focus on Faraday`s law of electromagnetic induction*.

The teacher started off by revisiting and verbally explaining the RHR concept and the big idea of MF before introducing the big idea of FL. TE2 then went on to introduce Faraday's law of electromagnetic induction while emphasising the interrelatedness to magnetic flux. In his introduction he started off by briefly explaining how Faraday devised the idea of induction.

TE2: *Now let us rap up this section by focusing on Faraday`s law of electromagnetic induction. Faraday`s law can be stated as follows: An emf is induced in the conductor whenever there is a change in the magnetic field due to relative motion between conductor and magnet. The induced emf is directly proportional to the rate of change of magnetic flux linkage.*

The teacher made full use of the whiteboard to present diagrams to aid his explanations of Faraday`s law. Figure 14 shows the teacher unpacking Faraday's law to his learners.

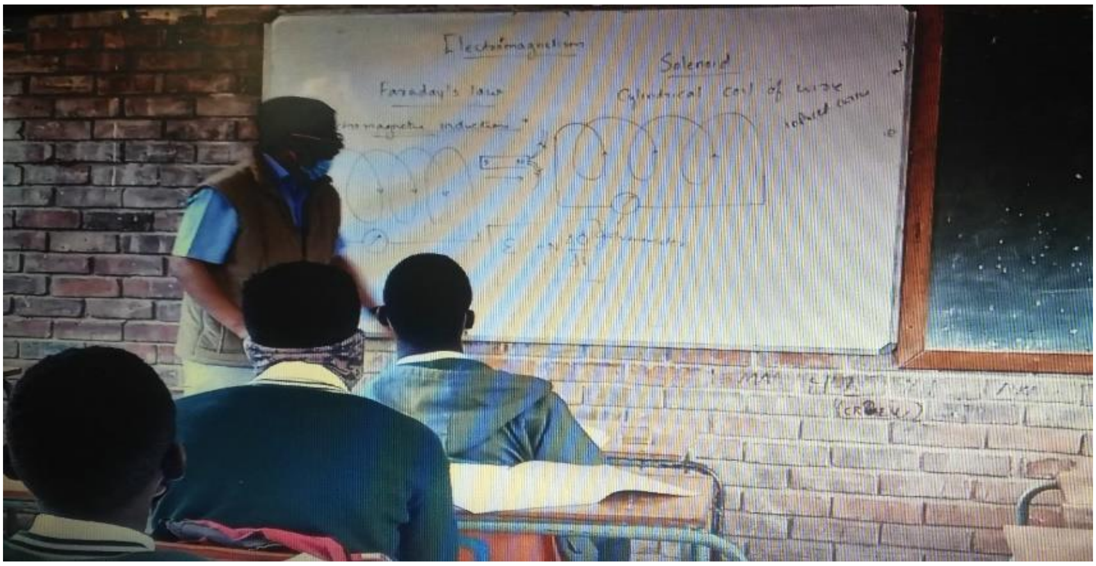


Figure 4.14: Screenshot showing a teacher unpacking the FL concept to his learners. Source: Researcher's own.

While still making full use of the chalkboard as a teaching aid, he then went on to present Faraday's law statement. This was followed by the mathematical formulations of Faraday's law

TE2: *In other words, Faraday`s law of electromagnetic induction has two facets. First facet focuses on induced emf due to relative motion between magnet and loop of wire. The second facet focuses on induced emf being directly proportional to rate of change of magnetic flux.*

This was followed by the mathematical formulations of Faraday's law

TE2: *The mathematical expression for Faraday`s law can be presented as:*

$$\varepsilon = \frac{-N\Delta\emptyset}{\Delta t}$$

The teacher also clarifies what each symbol in Faraday`s formula represents.

TE2: ε *= induced emf, the magnetic flux* $\emptyset = BAcos\theta$ *and N represents the number of coil turns. Any questions so far?*

Learner 3: *Since there is a negative sign in faraday`s law, does it mean that emf if a vector quantity?*

The teacher took the opportunity to explain the physical significance of the negative sign in Faraday's formula.

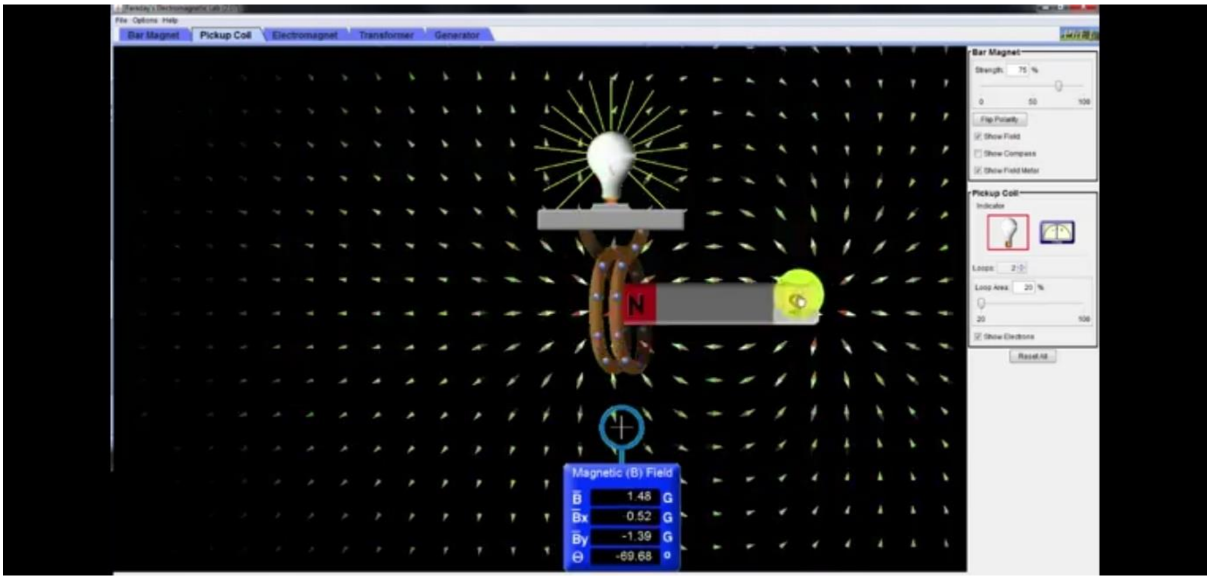
TE2: *No. no, no! emf is not a vector quantity and will never be a vector. The negative sign is prescribed to Lenz`s law. There is another law which is directly associated with Faraday`s law.*

It is referred to as Lenz`s law. Lenz`s law the primary reason as to why we have a negative sign in this formula. According to Lenz`s law, the negative sign has to do with the direction of the induced current due to a change in magnetic flux. The direction of the induced current can be predicted by using the right-hand rule. Meaning that Lenz`s law works hand and glove with the right-hand rule. Is that clear?

Section 4: Teaching the second big idea based on Faraday's law and EMI: PhET simulations [9 min 4 sec].

TE2: *Now let us observe the following PhET simulation presentation which I am going to show you and it`s based on electromagnetic induction.*

The simulation indicated that when a stronger magnet is used, greater current signal will be induced, and the bulb will glow as shown in figure 15.



Bar Magnet
Strength: 75 %
☑ Show Field
☐ Show Compass
☑ Show Field Meter

Pickup Coil
Loops: 2
Loop Area: 20 %
☑ Show Electrons

Magnetic (B) Field
B 1.48 G
Bx 0.52 G
By -1.39 G
θ -69.68 °

Figure 15

TE2: *What can you observe as the magnet moves inwards?*

Learner 5*: As magnet enters the loop, the bulb glows momentarily and then go off. But when magnet is pulled out in the opposite direction, the bulb glows again.*

TE2: *That's a good observation, this also means that as magnetic field strength increases, induced emf also increases. Increase in emf leads to an increase in current flow. What else?*

Learner 6*: The bulb only glows when there is relative motion, I mean only when the magnet is moving*

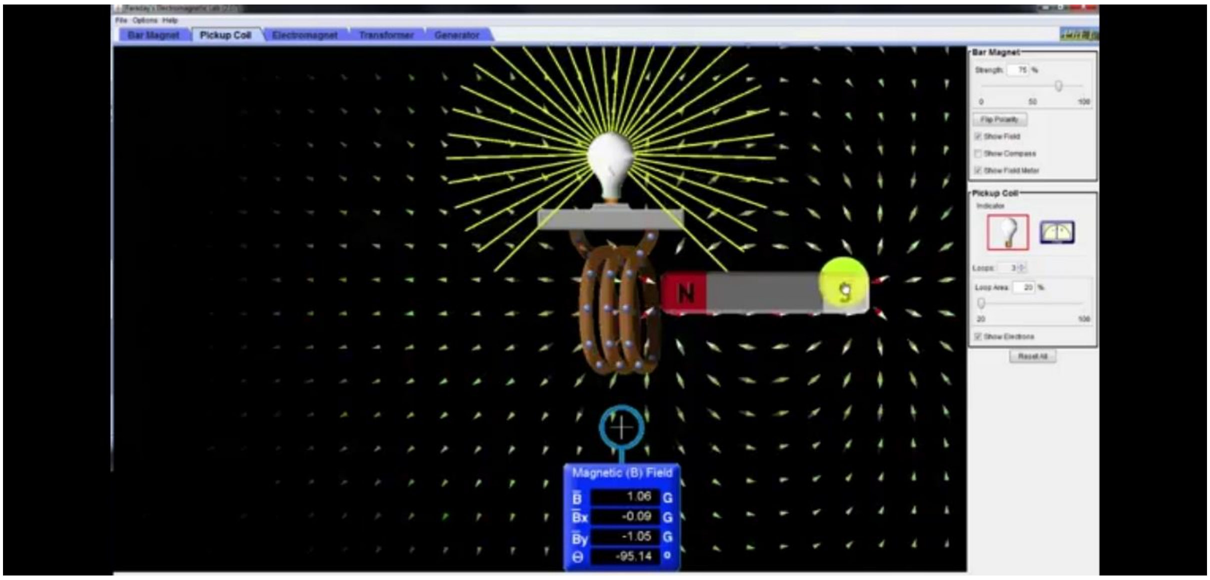
TE2: *Very excellent. What else can you observe?*

Learner 4: *There seems to be an interference of the magnetic field lines by the loop as the magnet moves in and out of the loop.*

TE2: *Very good observation. What about if the number of coil turns is increased?*

Learner 7: *The bulb produces more light. it gives more bright light.*

TE2: *That is correct meaning that as number of coil turns increases, induced emf also increased.*



Magnetic (B) Field
B 1.06 G
Bx -0.09 G
By -1.05 G
θ -95.14 °

Bar Magnet
Strength: 75 %
☑ Show Field
☐ Show Compass
☑ Show Field Meter

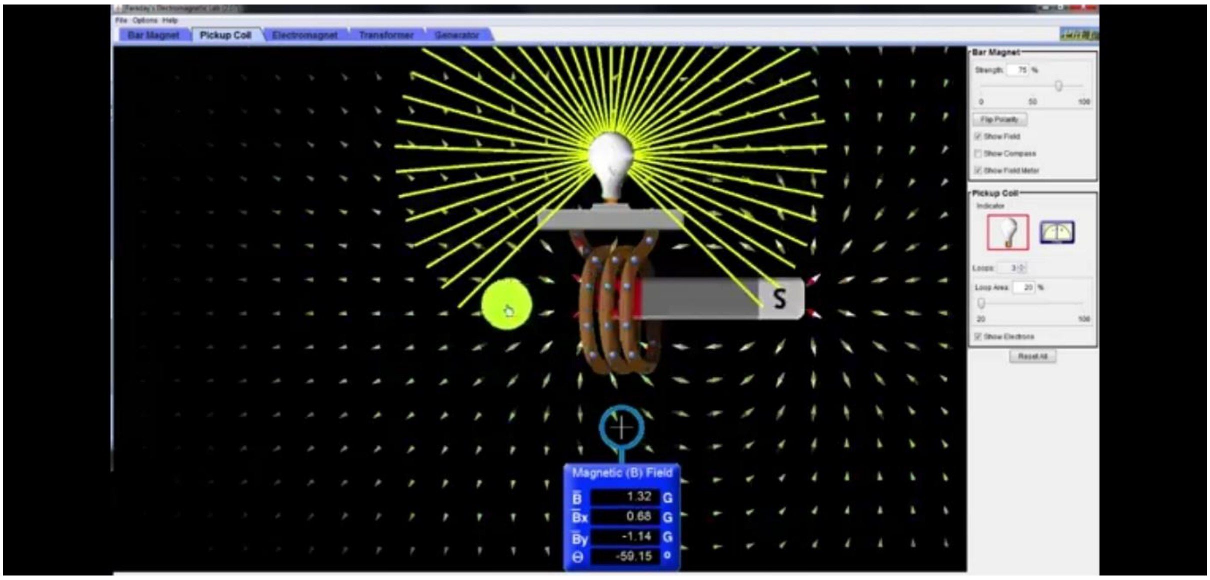
Pickup Coil
Loops: 3
Loop Area: 20 %
☑ Show Electrons

Figure 16

TE2: *That if the magnet moves rapidly into the loop*

Learner 8: *The brightness also suddenly increases.*

Teacher: that’s right. Meaning that the greater the speed, the higher is the amount of electricity we get.



Magnetic (B) Field
B 1.32 G
Bx 0.68 G
By -1.14 G
Θ -59.15 °

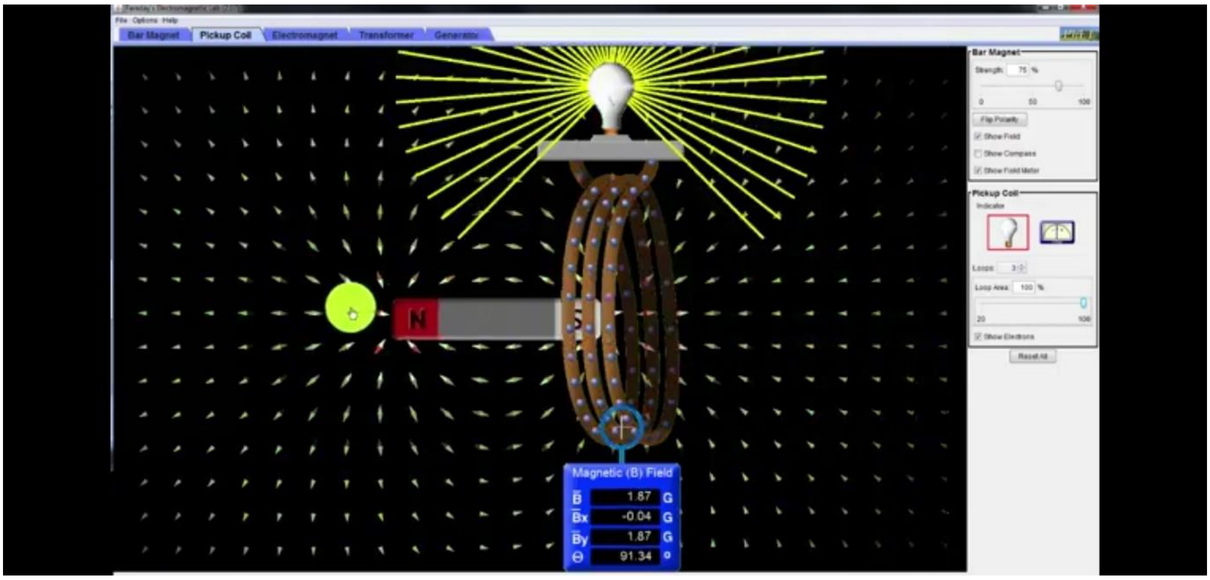
Figure 17

TE2: *Now what if we increase the cross-sectional area of the loop while maintaining the number of coil turn?*

Learner 2: *The brightness of bulb also further increases showing that as loop area increases, the magnitude of the induced emf also increases.*

TE2: *If you check the white arrow-shaped spots appearing on the simulation screen and passing through the loop, those arrows are representing MF. From my explanation, do you think it`s necessary to increase the cross-sectional area of the loop?*

Learner 5: *Yes. I think it allows magnetic flux through the loop to increase, thus leading to an increased emf output.*



Magnetic (B) Field
B 1.87 G
Bx -0.04 G
By 1.87 G
Θ 91.34 °

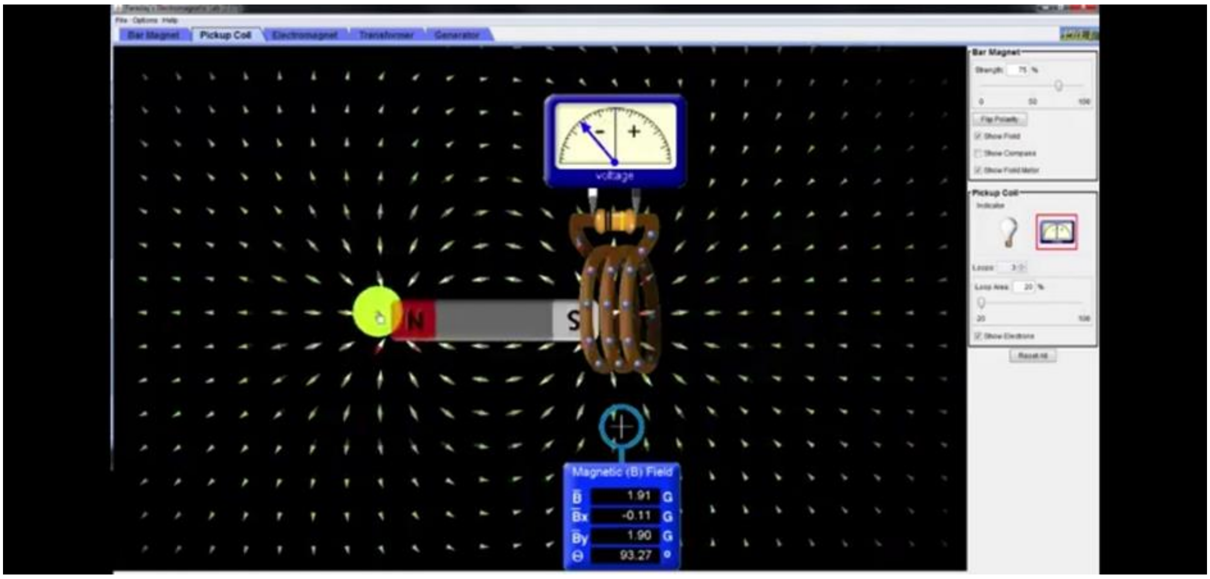
Figure 18

Learner 1: *what about if we want to take actual measurements? How is done using a simulation?*

TE2: *anyone with an idea of how this can be done*

Learner 5: *I think the bulb can be replaced with something like a voltmeter.*

TE2: *that is brilliant. Yes. We can simply replace the bulb with the centre zero galvanometer like this. In this case if a magnet is pushed inside the coil, the meter deflects to the left. The deflection is a result of induced current in the coil. The meter also indicates that the direction of the induced current opposes the motion producing it. Now watch this.*



Strength: 75 %

Loops: 3

Loop Area: 20 %

B 1.91 G

Bx -0.11 G

By 1.90 G

θ 93.27 °

Figure 19

TE2: *If the magnet is then pulled backwards, the meter will be deflected to the right indicating that the direction of the induced current is in the opposite sense in accordance with Lenz`s law.*

The teacher goes further to explain the physical meaning of the negative sign.

TE2: *I think you still remember the negative sign in Faraday`s formula. The negative sign represents the direction of induced current which opposes relative motion producing it. Also please note that the meter can only be deflected if either the magnet is moving into or out of the coil, or the coil is moving towards or away from the magnet, or both magnet and coil are moving towards or away from each other. That is what we call relative motion in physics.*

The PhET simulation presentation based on Faraday`s law of EMI was associated with lots of excitement as evidenced by higher levels of learner participation.

TE2: *Is there anyone with a question so far?*

All the learners are quiet, and no hand is up. Teacher then stops the simulations, shuts down his laptop, switches off the data projector and, then went on to give an example of how to perform numerical calculations based on the mathematical formulations of Faraday`s law. Teacher then gives learners a calculation problem based on Faraday`s law and requested them to attempt it as individuals. Meanwhile teacher moves around the class monitoring progress and, also attending to individuals with some questions related to EMI.

<u>Section 5</u>: Administration of class activity based on Faraday's law [13 min 7 sec]

The teacher went on to present some numerical calculation examples based on Faraday's formula on the chalkboard.

TE2*: Now can you please answer the following question based on Faraday`s law.*

He stressed the importance of change in magnetic field when calculating EMF.

TE2: *Please note that when performing calculations using Faraday`s law there might be need for you to start by calculating the change in magnetic field or change in magnetic flux. Can you please respond to the whole question in your classwork book as individuals. I will give very few minutes.*

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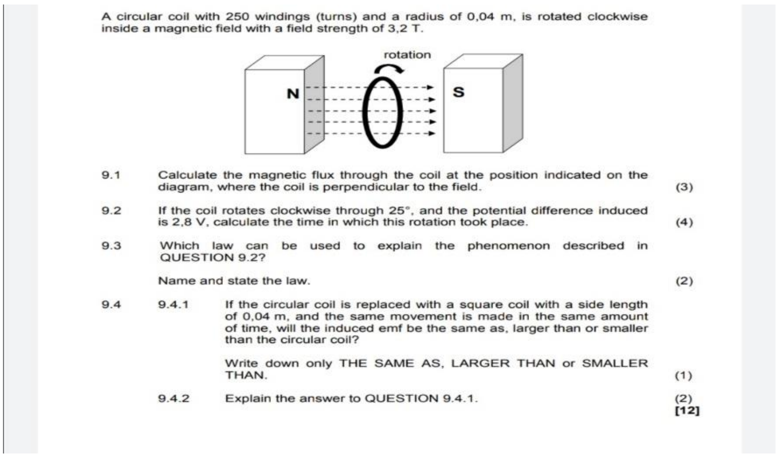


A circular coil with 250 windings (turns) and a radius of 0,04 m, is rotated clockwise inside a magnetic field with a field strength of 3,2 T.

9.1 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the field. (3)

9.2 If the coil rotates clockwise through 25°, and the potential difference induced is 2,8 V, calculate the time in which this rotation took place. (4)

9.3 Which law can be used to explain the phenomenon described in QUESTION 9.2?

Name and state the law. (2)

9.4 9.4.1 If the circular coil is replaced with a square coil with a side length of 0,04 m, and the same movement is made in the same amount of time, will the induced emf be the same as, larger than or smaller than the circular coil?

Write down only THE SAME AS, LARGER THAN or SMALLER THAN. (1)

9.4.2 Explain the answer to QUESTION 9.4.1. (2)
[12]

Figure 20: Snapshot of full question based on the big idea of FL. Source: Researcher's own.

Before the learners responded to the question in figure 21, the teacher made some remarks:

TE2: *Please note that this question is poorly structured. Actually, the field lines should pass through the loop. Here in this question, it seems like the loop is parallel to the magnetic field.*

That is not supposed to be the case. Where you don't understand please feel free to raise up your hand so that I can come and assist you.

While learners were busy with the class activities from their worksheets the teacher took the opportunity to assist individual learners with calculations and further explanations

<u>Section 6:</u> Concluding the lesson. [4min 03 sec]

Teacher then concludes the lesson by making the following remarks:

TE2: *From these PhET simulations based on EMI we observed that current in the loop increases and the bulb glows brighter if and only if: a stronger magnet (B) is used; number (N) of coil turns increases; cross-sectional area (A) of loop increases; magnet moves faster into or out of the coil. When the magnet stops moving, no induced current flows through the coil and bulb doesn't glow at all. It is also important at this time to note that Faraday`s law of electromagnetic induction is primarily used in most of the electricity generating plants throughout the world.*

More practice questions based on magnetic flux and Faraday`s law are then given to learners as part of their homework.

APPENDIX D3: VIDEO RECORDED LESSON OBSERVATIONS: TE3`S NARRATIVE ACCOUNT

Five sections were identified from his video recorded lesson. Having taught the Grade 11 section of electromagnetism for at least five years, he had developed his own pedagogical skills of handling the Grade 11 EMI section.

Section 1: Introduction revision of knowledge based on the previous lesson. [4min 03sec]

The introductory discussion touched briefly on recapping the activities of the previous lesson based on magnetic effect of a coil-carrying current.

TE3: *in our previous lesson we discussed the magnetic effect of a coil-carrying current. Who still remembers very well what it means when we say magnetic effect of a coil-carrying current?*

Learner 1: *I think it means that there exists a magnetic field around a current-carrying coil. This can be proven experimentally using a magnetic compass.*

TE3: *Very well said. Yes, I can see that there is another hand up.*

Learner 2: *I just want to add that electricity gives rise to magnetic effect.*

In his introduction, the teacher showed his learners a short video based on the EMI section (see figure 21).

TE3: *Now let us watch this video together so that you all can have the overview of what our lesson is about. Let`s all be quiet and observe.*

Figure 21 Screenshot of TE3 introducing electromagnetic induction. Source: Researcher's own.

TE3: *Now who can summarise what this video is all about.*

Learner 3: *It seems like there is a possibility of getting electricity from magnetic effect.*

TE3*: that is very correct observation*

Learner 4*: If a coil of wire is moved inside a magnetic field, some current will flow through the coil.*

TE3*: You are very correct*

Learner 5*: There is something called magnetic flux which associates itself with magnetic field lines passing through a coil of specific cross-sectional area. And when the coil tilts, less field lines are passing through leading to reduced magnetic flux.*

TE3: *That is a very wonderful and excellent explanation. I like the way you explained it. I am really pleased that you guys can pay attention. Now this makes it easier to treat today`s lesson. Now let us focus on magnetic flux.*

Section 2: Teaching the first big idea of MF [16min 25sec]

While introducing the first big idea of magnetic flux the teacher started by writing the definition of magnetic flux and the flux equation on the chalkboard.

TE3: *There are many ways of defining magnetic flux. But I prefer to define it this way.*

[redacted]

Figure 22: Screenshot of TE3 presenting the concept of MF. Source: Researcher’s own.

The teacher went on to verbally explain magnetic flux.

TE3: *……In other words, magnetic flux ∅ is a measure of the total magnetic field lines passing a loop of predictable cross-sectional area. The stronger the magnetic field B passing through an area of loop A, the higher the magnitude of the magnetic flux.*

He went on to explain the physical meaning of each symbol in the flux formula.

TE3: *In the flux formula, represents magnetic flux measured in webers (Wb), B represents magnetic field strength measured in teslas (T), The symbol A represents cross-sectional area of the loop and it's measured in square-metres. The angle* θ *represents the angle between the imaginary line drawn normal to the loop and the magnetic field. Is there anyone with a question so far?*

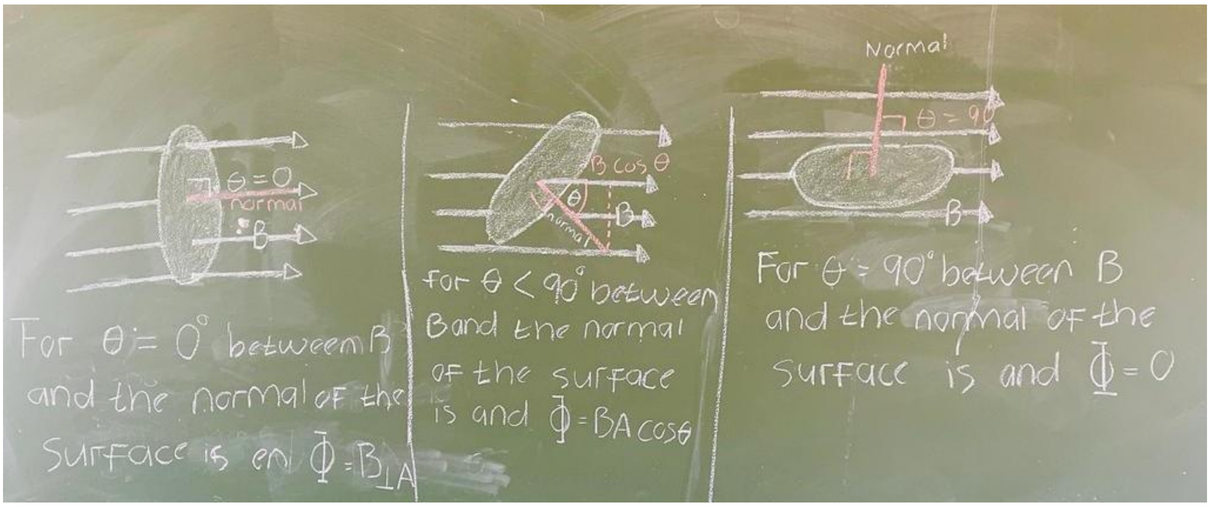
Learner 4: *What type of line is regarded as normal line?*

TE3: *That is a very good question. In Physics, Normal simply means perpendicular or right angle or* 90^0 *angle. If you remember very well, we once delt with a normal force in physics of mechanics. We defined normal force as a force exerted by a surface on an object and acts perpendicular to the surface. I hope it's now clear.*

He verbally explained the difference between magnetic field strength and magnetic flux.

TE3: *Magnetic field strength refers to a measure of the strength and direction of the magnetic field while magnetic flux refers to the product of component of magnetic field perpendicular to a surface and cross-sectional area of the loop in which the field passes through.*

The teacher used chalkboard diagrams shown in figure 23 while explaining the physical significance of the angle θ in the flux formula



For θ = 0° between B and the normal of the surface is en Φ = B⊥A

For θ < 90° between B and the normal of the surface is and Φ = BA cosθ

For θ = 90° between B and the normal of the surface is and Φ = 0

Figure 23: Snapshot showing diagrams used to explain angle θ. Source: Researcher's own.

TE3: *From the chalkboard diagrams, we can observe that if a line drawn (in red) normal to the loop runs parallel to the magnetic field lines it means that the angle θ will be zero. Now cos0 = 1 and the resultant magnetic flux will be maximum when angle $\theta = 0$. If the line drawn (in red) normal to the loop is 90^0 to the magnetic field, we achieve the minimum magnetic flux.*

Suddenly there is a hand up from one of the learners.

Learner 6: *How is that possible for magnetic flux to be zero yet we have increased the angle θ to 90^0?*

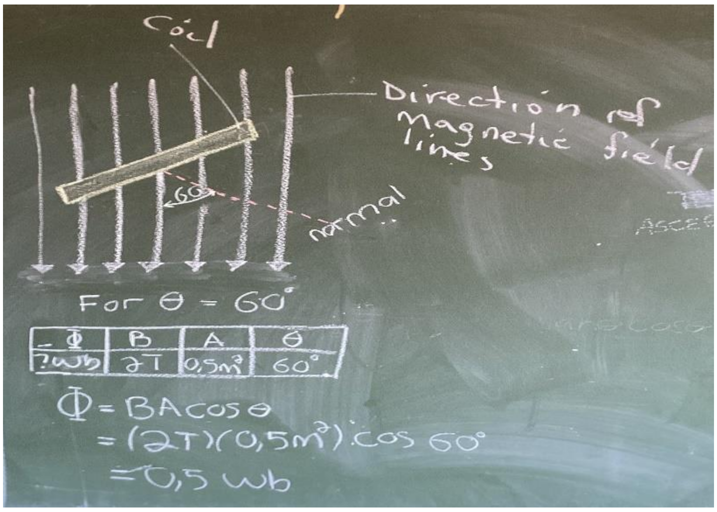
TE3: *It is a good clarity-seeking question. Now I want you to all listen very carefully. The formula for magnetic flux is:* $\emptyset = BAcos\theta$

Now if the angle $\theta=90$, it means that cos90=0. If you substitute with 90 in the formula you will realise that the resultant magnetic flux = 0. When the angle θ starts to decrease from 90^0 towards 0^0, the resultant magnetic flux will be increasing to its maximum. I hope my explanation mathematically makes sense.

Class: *Yes sir.*

TE3: *Now let us go through an example so that you can all learn how to perform calculations using the flux formula.*

A worked example shown in figure 24 was then conducted on the chalkboard to enable learners to use the flux formula.



For $\theta = 60°$

Φ	B	A	θ
?Wb	2T	$0,5m^2$	60°

$\Phi = BA\cos\theta$

$= (2T)(0,5m^2)\cos 60°$

$= 0,5$ Wb

Figure 24: Snapshot showing diagram used to perform a calculation based on 60^0 angle. Source: Researcher’s own.

The teacher placed more emphasis on the importance of angle θ during numerical calculations.

TE3: *Please take note of the angle between a line drawn normal to the loop and the magnetic field when performing calculations using flux formula. The other thing is that, make sure you calculate loop area in square metres.*

He then requested his learners to attempt two questions based on magnetic flux from their textbook. While the learners were busy responding to the questions in their class work books, the teacher moved around monitoring progress and assisting learners with some individual challenges based on MF.

Section 3: Teaching the second big idea of FL [18min 12sec]

TE3 went on to introduce the concept of electromagnetic induction and Faraday's law while linking it with magnetic flux. In his introduction, he started by showing learners a short video based on Faraday's law of electromagnetic induction followed by teacher led class discussion.

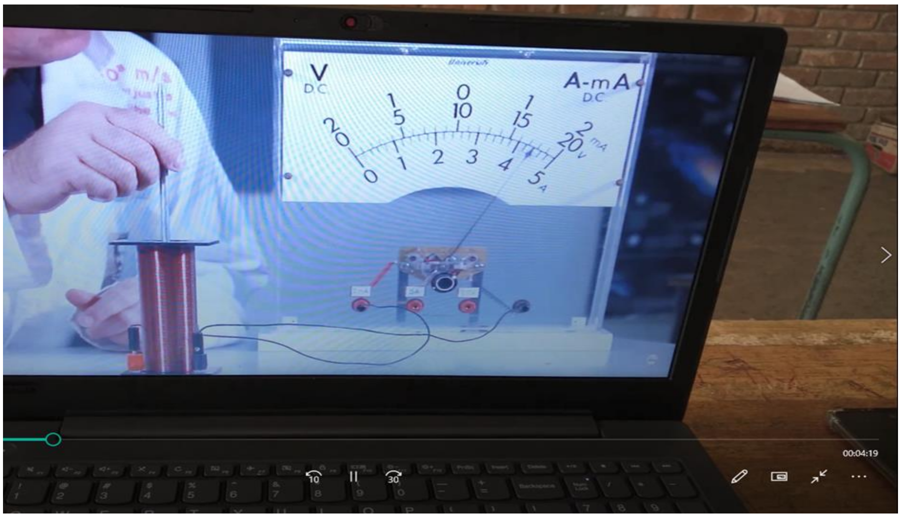


Figure 25: Screenshot of the video simulation used to introduce Faraday's law. Source: Researcher's own.

TE3: *Now from the video we have just watched, let us try to discuss the main points or summary being depicted by the video.*

Learner 7: *When a magnet is moved inside or out of the coil, a reading is registered on the voltmeter.*

TE3: *Yes, that is very correct. Anything else.*

Learner 5: *A faster movement of the magnet leads to a greater deflection. But if the magnet is held stationary then the voltmeter reading is zero.*

TE3: *That's brilliant. I like the explanations. In other words, this video shows the set-up which was an original idea in Faraday`s mind. The same idea today is primarily being exploited to generate electricity throughout the world.*

The teacher practically attempts to demonstrate electromagnetic induction by moving a bar magnet over a coil of copper wire connected to a voltmeter.

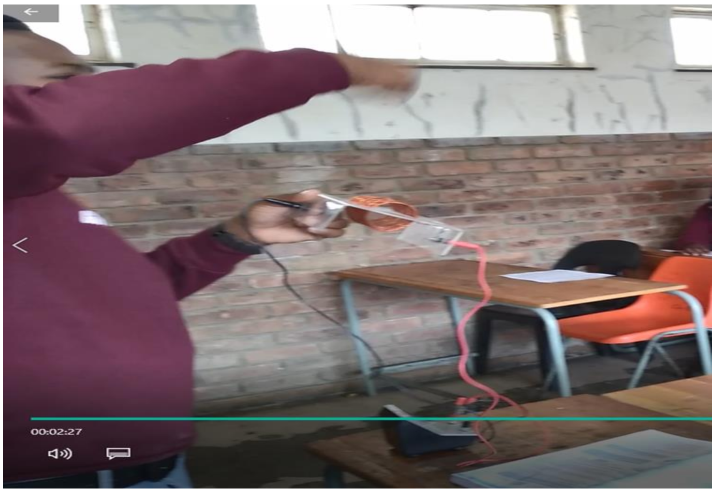


Figure 26: Screenshot showing teacher trying to demonstrate the induction principle. Source: Researcher's own.

However, no deflection on his voltmeter was noted. He said to his learners:

TE3: *Unfortunately, there is no reading being shown on the voltmeter. I think the magnet is very weak. These magnets have been in the laboratory for a very long time before all of us were born. I shall try and look for a stronger magnet and demonstrate it to you again.*

One learner raises up his hand to ask a question.

Learner 3*: Sir, so will there be any reading on the voltmeter if the coil is moved instead of the magnet?*

TE3: *That's a very good question. Let us hear from the class. Maybe someone in this class will tell us the correct answer.*

Learner 5: *I think the voltmeter will register a reading as long as there is movement of either the magnet or coil or both. But if there is no movement, then there will be no reading.*

TE3: *That is a wonderful explanation. I hope the whole class is satisfied with the answer.*

Class: *Yes.*

TE3*: In other words, emf can only be induced if and only if there is some sort of relative motion between coil and magnet.*

The teacher went on to write Faraday's law statement as well as the formula on the chalkboard. He also verbally explained the physical significance of each symbol in the formula.

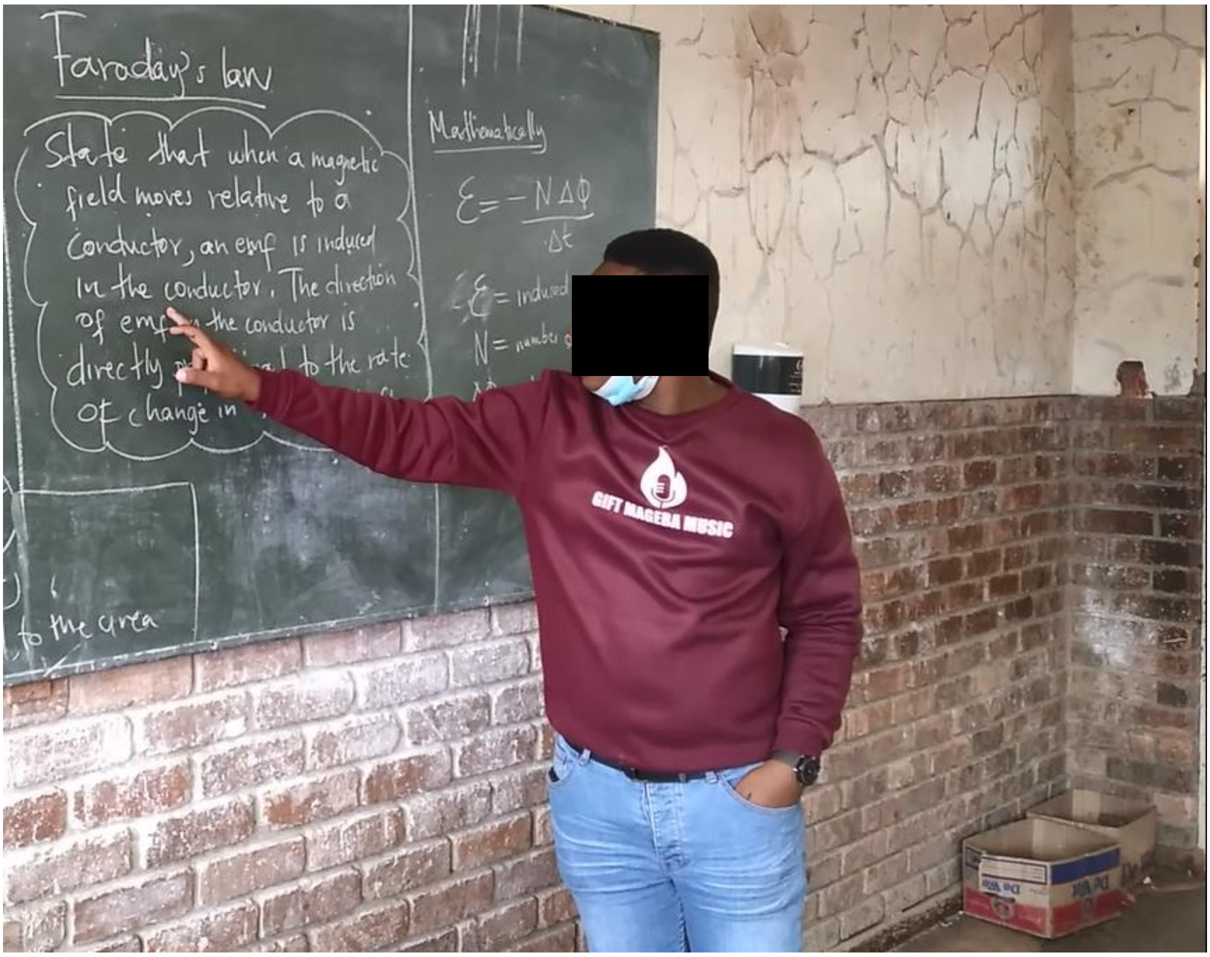


Figure 27: Screenshot showing TE3 using chalkboard notes to explain Faraday's law. Source: Researcher's own.

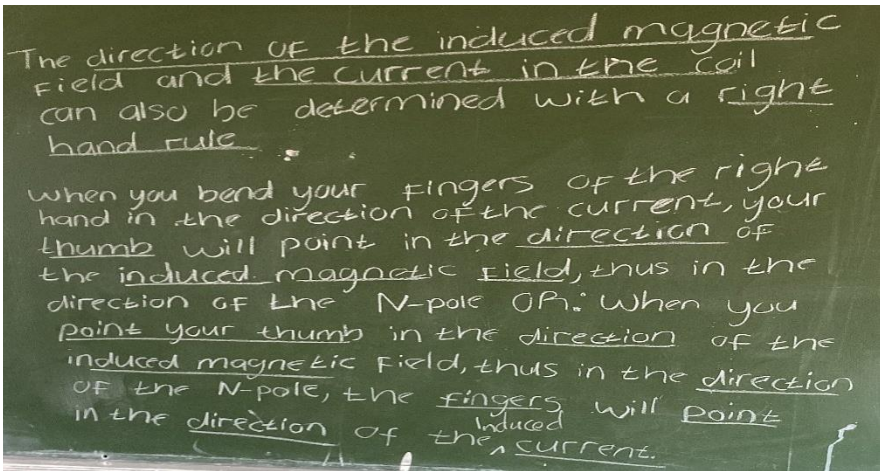
TE3: *In Faraday`s formula, N represents number of coil turns, ε represents the induced electromotive force or voltage, Δt represents the time taken during flux change or the rate of flux change.*

One learner raises up a hand to ask a question and the teacher recognises the learner.

Learner 2: *Is that negative sign supposed to be there, or you made a mistake by including it?*

TE3: *No, it is not a mistake. Faraday`s electromagnetic induction formula has a negative sign. This means that the negative sign in Faraday's formula has to do with the direction of induced current which is predicted using Lenz's law. The induced current also creates a magnetic field around the coil whose polarity can be predicted by applying the right-hand rule.*

The teacher then went on to verbally explain Faraday’s law with the aid of chalkboard notes in conjunction with RHR and Lenz’s law.



The direction of the induced magnetic field and the current in the coil can also be determined with a right hand rule.

When you bend your fingers of the right hand in the direction of the current, your thumb will point in the direction of the induced magnetic field, thus in the direction of the N-pole OR. When you point your thumb in the direction of the induced magnetic field, thus in the direction of the N-pole, the fingers will point in the direction of the induced current.

Figure 28: Snapshot of chalkboard notes used to explain RHR and direction of current. Source: Researcher’s own

Section 4: Teaching second big idea of FL using video simulations [17mins 24s]

TE3: *Now let us observe again some video simulations associated with Faraday`s law. What can you say about this clip?*

Learner 1: *There is a deflection on the galvanometer when a bar magnet moves towards and into the coil.*

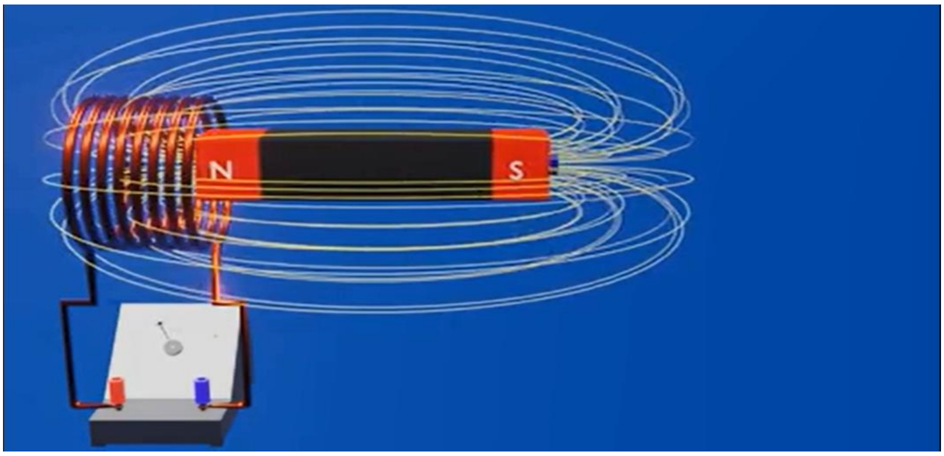


Figure 29: Screenshot showing induced current due to movement of magnet.

TE3: *That is true. What else?*

Learner 8: *The deflection only occurs when the magnet is moving towards the coil. When the magnet was held stationary inside the coil, there is no deflection on the galvanometer.*

TE3: *What is the reason for the galvanometer to read zero.*

One of his learners is quick to respond

Learner 9: *I think it is because the magnet is no longer moving. But if the magnet keeps on moving inside the coil the galvanometer will give us a reading.*

TE3: *Yes, that is correct. If there is no relative motion, then no emf is induced. Now what can you observe?*

Learner 10: *When the bar magnet is pulled out of the coil, there was a deflection on the galvanometer but in the opposite direction.*

The teacher also took this opportunity to re-emphasise on the first big idea of MF saying that:

TE3: *I think you can all observe the white strands of lines around the bar magnet. They represent magnetic field lines. Please note that those field lines passing through the coil during relative motion are representing magnetic flux. The more field lines we have passing through the coil, the greater the magnetic flux.*

During the simulated videos, a question was raised by learner:

Learner 3: *So, does it mean that the induced current only due to relative motion between coil and magnet?*

TE3: *No, not necessarily coil and magnet in relative motion. Even a current-carrying coil can give rise to a change in magnetic flux.*

The teacher used another video simulation shown in figure 30 to further explain how current is induced.

TE3: *Look at this video clip and observe carefully what happens.*

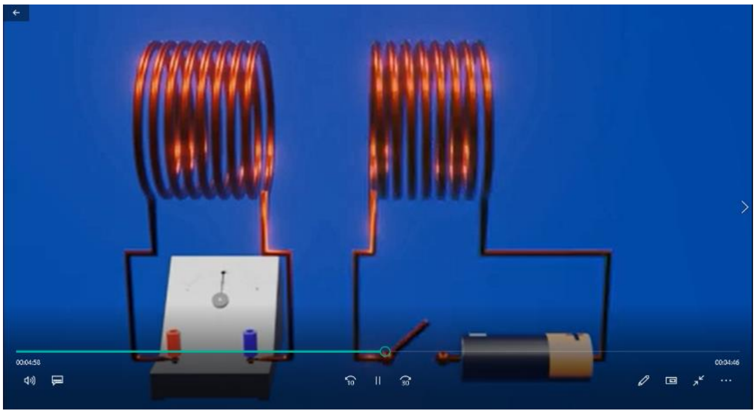


Figure 30: Screenshot showing induced current due to change in magnetic flux.

The teacher opened and closed the switch in the second coil to produce a change in magnetic flux.

TE3: *I think you can see that it is not only a magnet that gives rise to a change in magnetic flux. Therefore, the reason that Induced current is mainly due to change in magnetic flux and not due to motion of magnet*

He went further to explain with the aid of another video simulation.

TE3: *The direction of the induced current can be explained in terms of Lenz`s law and direction of the induced magnetic field in terms of the right-hand rule.*

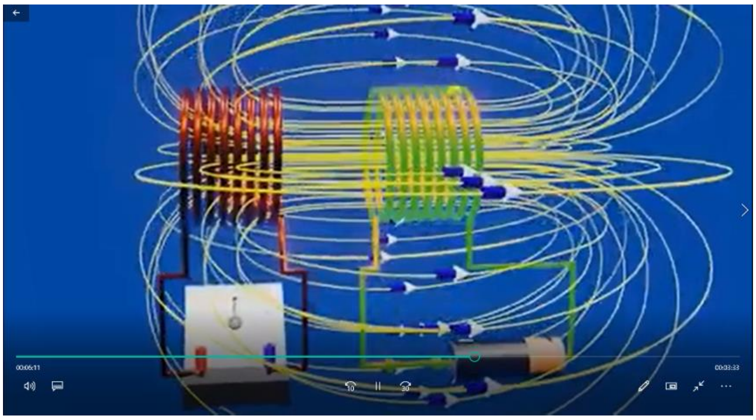


Figure 31: Screenshot showing simulation diagram used to explain RHR and Lenz`s law.

TE3: *A closer look at the video simulation also tells us that the induced magnetic field opposes that of the approaching magnet and change in flux*

The teacher used another video of simulation shown in figure 31 to explain Lenz`s law.

TE3: *I think you can observe that the direction of the induced current always opposes motion producing it.*

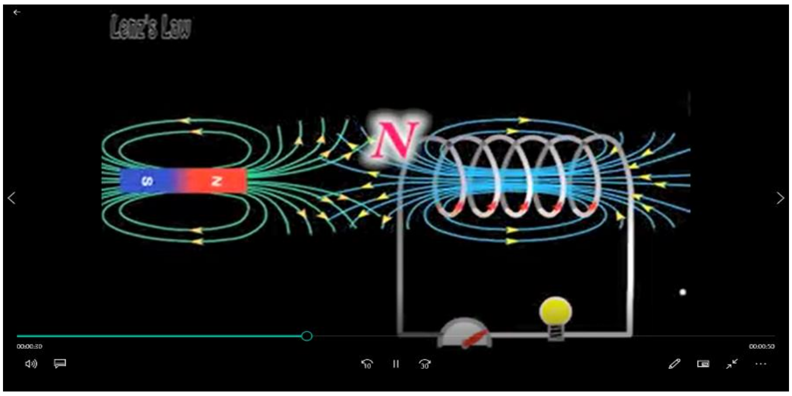
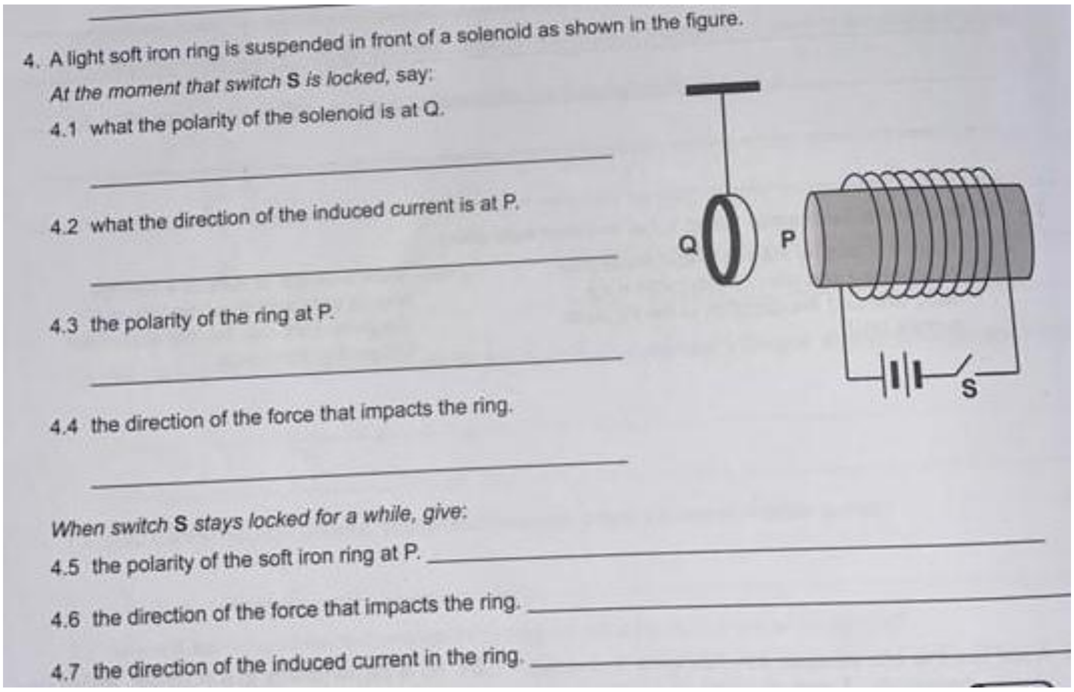


Figure 31: Screenshot showing simulation diagram used to explain Lenz`s law.

TE3: *To predict the direction of the induced current we apply the right-hand rule. Please note when current is induced in the coil, it creates its own magnetic field around the coil. Therefore, we apply the right-hand rule to the magnetic field of the induced current and not magnetic field of the bar magnet.*

Furthermore, he gave learners 2 worked examples based on numerical calculations before giving them some questions to attempt as individuals in their classwork books.

TE3: *Can you please try to answer this question as individuals in your classwork books.*



4. A light soft iron ring is suspended in front of a solenoid as shown in the figure.

At the moment that switch **S** *is locked,* say:

4.1 what the polarity of the solenoid is at Q.

4.2 what the direction of the induced current is at P.

4.3 the polarity of the ring at P.

4.4 the direction of the force that impacts the ring.

When switch **S** *stays locked for a while,* give:

4.5 the polarity of the soft iron ring at P.

4.6 the direction of the force that impacts the ring.

4.7 the direction of the induced current in the ring.

Figure 31: Snapshot of question given to learners based on FL

Section 4 Conclusion [3mins 29s]:

The teacher then concluded the lesson by providing a brief summary of the entire lesson.

TE3*: In our lesson today, we were able to define and demonstrate magnetic flux as well as electromagnetic induction using video simulations. We also discussed Faraday`s law and how it is linked to Lenz`s law and the right-hand rule.*

He also gave mention of the application of EMI in electric generators.

TE3: *It also important for you to recall that most generators operate by Faraday`s law of electromagnetic induction.*

Homework was given based on both magnetic flux and Faraday`s law.

APPENDIX D4: VIDEO RECORDED LESSON OBSERVATIONS: TE4`S NARRATIVE ACCOUNT

The following is a detailed narrative account of what actually transpired during TE4`s lesson based on EMI as captured in the video recordings.

Section 1: Introduction [3mins 22s]

In her introduction, TE4 began with a brief reflection of the previous lesson`s ideas based on electric field around a straight conductor and solenoid carrying current. The reflection reminded learners that a current through a conductor induces a magnetic field around a conductor. In her introduction, she also revisited the right-hand rule and its application in predicting direction of the induced magnetic field.

Teacher starts the lesson by asking questions related to what she has already covered with the learners.

TE4: *Do you still recall what we did in our previous lesson pertaining electricity and magnetism?*

Class: *Yess Mem.*

TE4: *what did we say? Who can remind us?*

Learner 1: *There is a magnetic field existing around a current carrying conductor.*

TE4: *Yes. What else?*

Learner 2: *We apply the right-hand rule if we want to determine the direction of the field.*

TE4: *Yes, that is correct.*

Teacher then went on to demonstrate right hand by using and holding a ruler in her right hand.

TE4: *Imagine this ruler i am holding in my right hand like this. With my thumb pointing forward and parallel to the length of the ruler like this while all the other fingers are curled around it like this. Then the thumb will always give us the direction of the current while the curled fingers give us the direction of the field. So, who can tell me in which direction is the magnetic field if I am holding the ruler vertically with my thumb pointing upwards.*

Suddenly most of the learners raise up their hands to respond to the questions. Then teacher requests one learner to respond

TE4: *That means you all know the answer. In this case the current flows in an anticlockwise direction, isn’t it?*

Class: *Yes*

The teacher did not give the learners to respond to the question as individuals. She then goes to talk about the RHR application in a solenoid.

TE4: *In which other situations do we apply the right-hand rule? when trying to determine the direction of the magnetic field in a solenoid isn't it?*

Class: *Yes.*

The teacher then responds to her own questions,

TE4: *Correct. So, do we apply it the same way as in a straight conductor?*

Class: *No.*

The teacher again did not give learners chance to respond. She responded to her own questions. The class is only given the chance to respond in chorus way. The teacher goes on to explain.

TE4: *the curled fingers if held around the solenoid points in the direction of the current while the thumb will give us field direction. Which means in our previous lesson we were discussing the magnetic effect of an electric current. In other words, electric current through a conductor can give rise to magnetic field around the conductor regardless of whether the conductor is straight or a loop.*

Section 2: Teaching the big idea of magnetic flux [25mins 05s]

The teacher went on to verbally introduce the new concept of magnetic flux for the first time.

TE4: *I am first gonna tell your about magnetic flux and its associated calculations and, later on I will introduce to you Faraday`s law of electromagnetic induction. Magnetic flux is a scalar quantity. It is also a product of the component of magnetic flux density and area of the loop. You remember in mechanics we talked about components of force? Even in magnetic flux density we talk about components of magnetic field also.*

Suddenly a learner`s hand is up?

Learner 2: *Excuse me Mem. I have a question. In mechanics we delt with components of vectors. So, does it mean to say that we also have vectors here?*

TE4: *That's a very good question. Who can try and respond to that question?*

Another learner requests to attempt to respond.

Learner 3: *I think magnetic field strength is a vector since it has component as Mem said.*

TE4: *Yes. that is true. Magnetic field is a vector quantity.*

The teacher then goes further to present on the chalkboard the definition of magnetic flux and mathematical formula used in calculating magnetic flux as shown in figure 32

Figure 32: Screenshot showing TE4 using chalkboard notes to explain magnetic flux.

The teacher went on to write the flux formula on the chalkboard as also shown in figure 32

$$\emptyset = BCOS\theta A$$

She then goes further to explain the meaning of symbols in the formula.

TE4: *Now this first symbol* $\emptyset$ *is represent the magnetic flux. Magnetic flux is measured in webers and the symbol for webers is Wb. The symbol B in the formula represents the magnetic field strength, and it is measured in teslas. The symbol of tesla is a capital T. The angle* θ *is the angle between magnetic field and a line normal to the loop; The symbol A represent the cross-sectional area of the loop of wire. In physics area is measured in square meters*

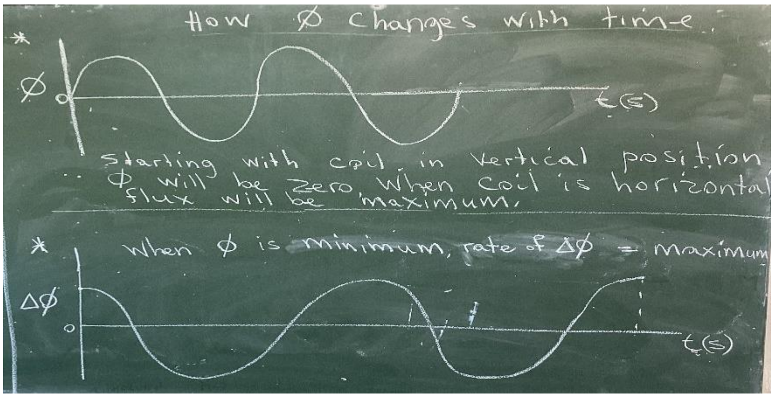
Another hand from the class is up. The teacher acknowledges the learners and allows her to speak.

Learner 4: *what is the difference between magnetic flux and magnetic field strength?*

TE4: *It's a good question. But I thought I had already answered the question. Anyway, first of all, magnetic flux is a scalar and magnetic field strength is a vector. Yes of course there is difference between magnetic flux and magnetic field strength. Magnetic field strength only refers to the density and direction of the magnetic field. while magnetic flux is a product of loop* *area and component of magnetic field strength. But we are going to primarily focus especially on flux and change in magnetic flux. I hope it's now clear.*

Class: *Yes.*

The teacher went further to draw some graphs shown in figure 33 on the chalkboard and used them to show how flux changes when a loop rotates in a magnetic field.



Starting with coil in vertical position
∴ Ø will be zero, When coil is horizontal
flux will be maximum.

When Ø is minimum, rate of ΔØ = maximum

Figure 33: Snapshot showing graphs used to explain the difference between flux and flux change

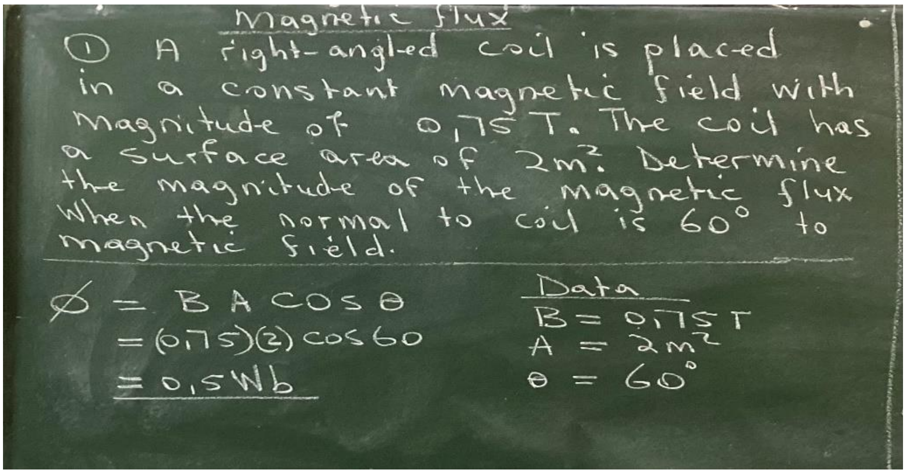
TE4: *Please observe from the graphs that when coil is vertical flux change is maximum and flux will be zero. When coil is horizontal, flux is maximum and the change in flux will be zero.*

Teacher gives a chalkboard example based on how to calculate using flux formula.

TE4: *Now, I am going to lead you in one or two examples related to numerical calculations of magnetic flux on the chalkboard. Then afterwards I will ask you to quickly attempt two more questions from your worksheet into your classwork book. Is that ok?*

Class: *yes Mem.*

The teacher went on to lead a class discussion related to the calculation of the magnetic flux as shown in figure 34



Magnetic flux

① A right-angled coil is placed in a constant magnetic field with magnitude of 0,75 T. The coil has a surface area of 2m². Determine the magnitude of the magnetic flux when the normal to coil is 60° to magnetic field.

$\emptyset = BA\cos\theta$

$= (0{,}75)(2)\cos 60$

$= 0{,}5\,Wb$

Data

$B = 0{,}75\,T$

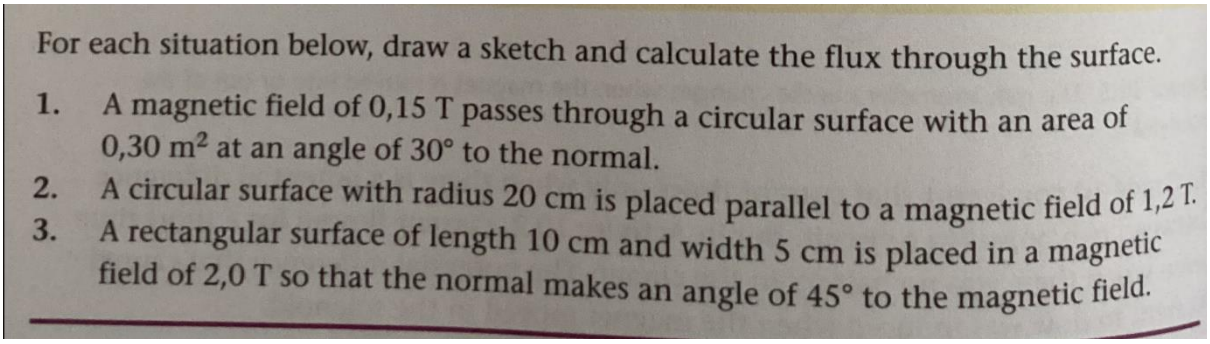
$A = 2m^2$

$\theta = 60^\circ$

Figure 34: Snapshot showing an example of numerical calculation based on magnetic flux

The teacher then went on to give classwork activity to learners related to the same section. She then gave the learners some questions shown in figure 35 based on calculation of magnetic flux from the worksheet.

TE4: *can you please quickly answer questions 1, 2 and 3 from the worksheet that I just gave you into your classwork books. I am only giving you about 10minutes to answer all of them.*



For each situation below, draw a sketch and calculate the flux through the surface.

1. A magnetic field of 0,15 T passes through a circular surface with an area of 0,30 m² at an angle of 30° to the normal.
2. A circular surface with radius 20 cm is placed parallel to a magnetic field of 1,2 T.
3. A rectangular surface of length 10 cm and width 5 cm is placed in a magnetic field of 2,0 T so that the normal makes an angle of 45° to the magnetic field.

Figure 35: Snapshot showing a question given to learners as individual class activity based on MF.

TE4: *Please try your best to answer the questions as individuals and to the best of your knowledge.*

While the learners were busy responding to the questions in their classwork books, TE4 moved around monitoring progress and assisting individual learners. After approximately 10 minutes, the teacher TE4 interrupts the learners.

TE4: *Can you please stop whatever you are doing. I think I have given you enough time to respond to the questions in the worksheet. I hope you all managed to get the answers to the three questions correctly. Is there anyone who had a challenge in answering any of the questions?*

Section 3: Teaching the second big idea of Faraday`s law [28mins 10s]

The teacher went on to introduce Faraday`s law of electromagnetic induction to her learners.

TE4: *Now, let us move on to the next section which is about Faraday`s law of electromagnetic induction. If you remember we did the magnetic effect of an electric current in our previous lesson. Let me start by checking. So, who can define magnetic flux for us? What is magnetic flux?*

Learner 3: *Magnetic flux is a product of loop area and component of magnetic field strength*

TE4: *very correct. Now Faraday` s law is focusing on the scientific principle that an electric current signal can be induced from magnets. In his statement of the law Faraday said:*

"Whenever there is a change in the magnetic field surrounding a conductor, an emf is induced in the conductor. The magnitude of the induced emf is directly proportional to the rate of change of magnetic flux cutting across the circuit."

Teacher goes further to paraphrase Faraday`s law statement.

TE4: *In other words, we need relative motion to exist between the coil and the magnet for electricity to be induced in the coil. Which means, no relative motion, no induced emf. No current signal produced. The faster the relative motion, the greater is the induced emf.*

There is a hand up from one of the learners.

Learner 5: *Sorry Mem. What is actually meant by relative motion?*

TE4: *Okay. Relative motion simply means that either we can generate the electricity by moving the magnet into and out of the coil without moving the coil or we can generate the electricity by moving the moving the coil towards or away from the magnetic field, I mean by making the coil to constantly interfere with the magnetic field lines while the magnet is not moving. Is that clear?*

Class*:* *Yes.*

She then wrote Faraday`s mathematical formula on the chalkboard as:

$$\varepsilon = \frac{-N\Delta\emptyset}{\Delta t}$$

She then went on to explain the physical significance of each symbol in the formula as shown in figure 36

Figure 36: Screenshot showing TE4 using chalkboard notes to explain Faraday`s law

TE4: *The symbol* ε *= represents the induced emf and its units are volts. Don't forget that emf is actually the total voltage. The symbol* $\Delta\varnothing$ *in the numerator represents a change in magnetic flux where* $\emptyset = BAcos\theta$ *and it's measured in webers. The capital N represents the number of coil turns. I think you can see a negative sign in the formula. This is the only formula I know of in physics which has a negative sign in it. So please when using this formula, don't forget that there is a negative sign. She then went on to write the statement of Faraday`s law on the chalkboard after explaining symbols in the formula. Any questions so far?*

There is a hand up from one learner and teacher allows the learner to ask.

Learner 6: *But where does the negative sign in Faraday`s formula come from?*

The teacher confidently responded to the question saying:

TE4: *Don't worry about the negative sign. Just don't forget to include it when you are performing your calculations because it's part of Faraday`s formula.*

The learner who asked the question seemingly not convinced with the teacher`s response. shakes his head.

Another learner`s hand is up, and teacher immediately gives audience to the learner.

Learner 3*: I want to try and provide an explanation pertaining the negative sign. I think the negative sign has to do with the direction of the induced current which can also be predicted by using Lenz`s law.*

TE4: *That's a very brilliant explanation. I am impressed. Class, let us clap hands for him for giving us such a wonderful explanation.*

The teacher now goes on to talk about the significance of change in flux in Faraday`s formula.

TE4: *Now, the main reason why we had to start by dealing with magnetic flux and some calculations using the flux formula is because Faraday`s law deals with change in magnetic flux. I think you can all see that the numerator part of Faraday`s formula contains a change in magnetic flux. And I think you can also see that there is a negative sign in the formula. Always make sure that in all your calculations you don't forget the negative sign. Even when you are writing the test or exam, they will always be a formula sheet and the formula for Faraday`s law will be given exactly like this in the formula sheet also. Do we have any questions so far?*

Suddenly the whole class goes silent. Then one learner raises up his hand.

Learner 2: *What about if you want to increase the induced emf, what is done to make sure that we get a lot of emf being induced?*

TE4: *That's a good question. You have actually asked something which I was about to present to the class.*

The teacher then went on to explain the ways that can be used to increase the magnitude of the induced emf with the aid of sketch graph presented on the chalkboard starting with the one shown in figure 37.

TE4: *consider this graph of emf versus change in magnetic flux.*

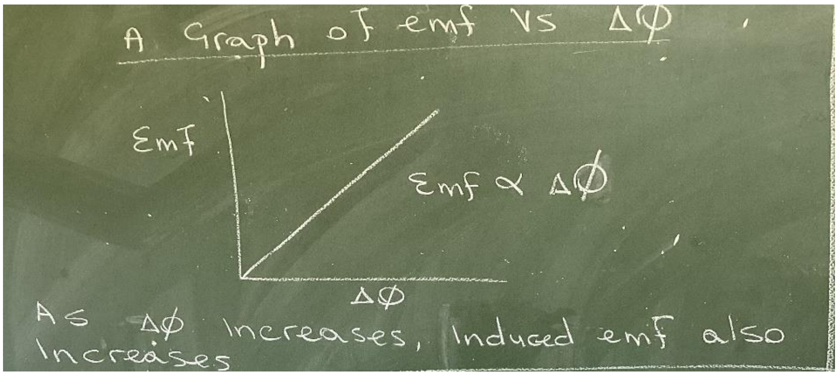


Figure 37: Snapshot showing graph used to explain the relationship between emf and flux change.

TE4: *As you can see from this graph that an increase in flux change consequently leads to an increase in emf. This means that what matters most for current to be induced in the coil is not just the magnetic flux but the change in magnetic flux.*

The teacher goes on to present a second graph as shown in figure 38

TE4: *Now, let us consider this second graph showing a relationship between emf and number of coil turns.*

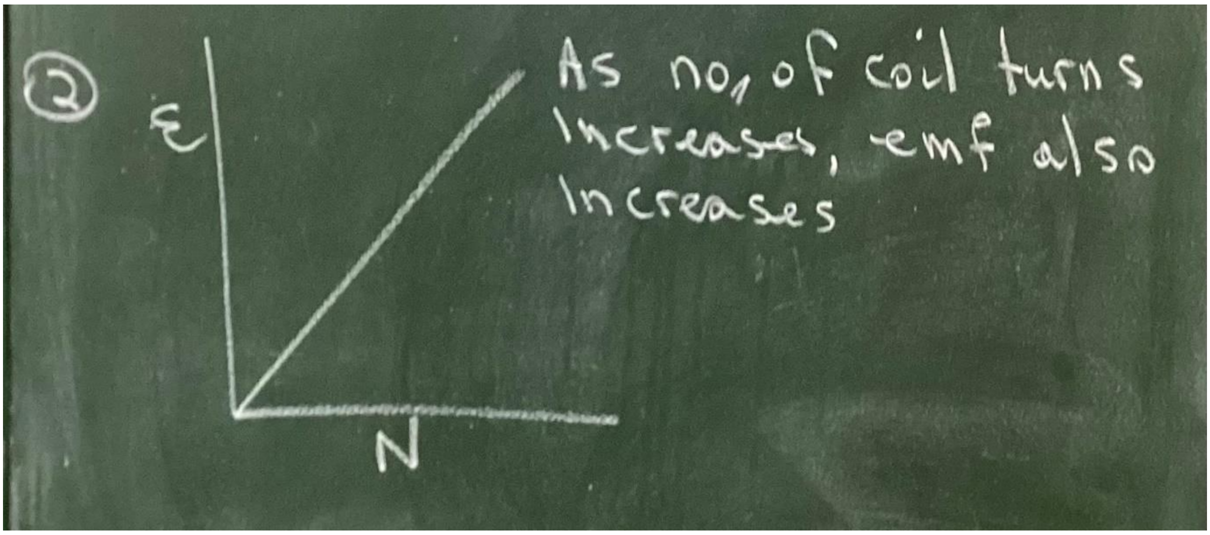


Figure 38 Snapshot showing graph used to explain the relationship between emf and number of coil turns.

TE4: *What this graph is simply telling us is that the more coil turns you have, the greater is the induced emf. there is a linear relationship between number of coil turns and the induced emf. Is that clear?*

The teacher proceeds to present a third graph as shown in figure 39

TE4: *Now, let us see how whether the magnetic field strength has an effect on the magnitude of the induced emf.*

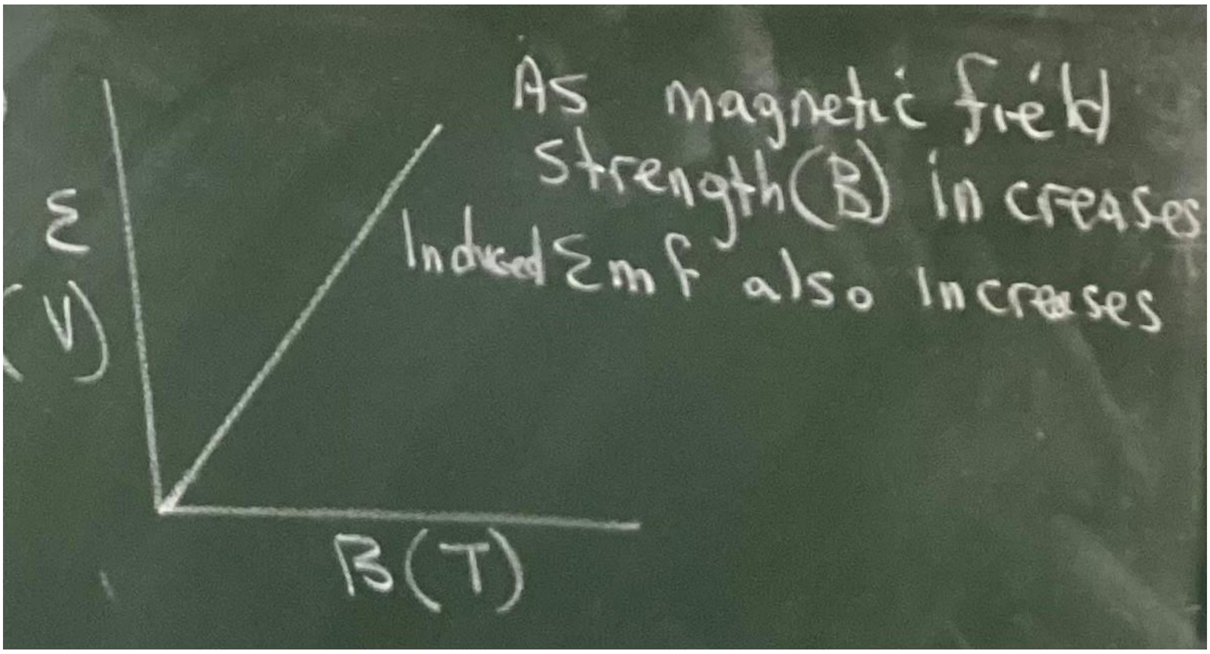


Figure 39: Snapshot showing graph used to explain the relationship between emf and magnetic field strength.

TE4: *As you can see from this graph that, an increase in magnetic field strength will consequently result in an increase in induced emf. Again, there exists a linear relationship between magnetic field strength and induced emf.*

The goes further to present another graph as shown in figure 40

TE4: *Now, we can also show a relationship that exists between the cross-sectional area of the coil or loop and emf.*

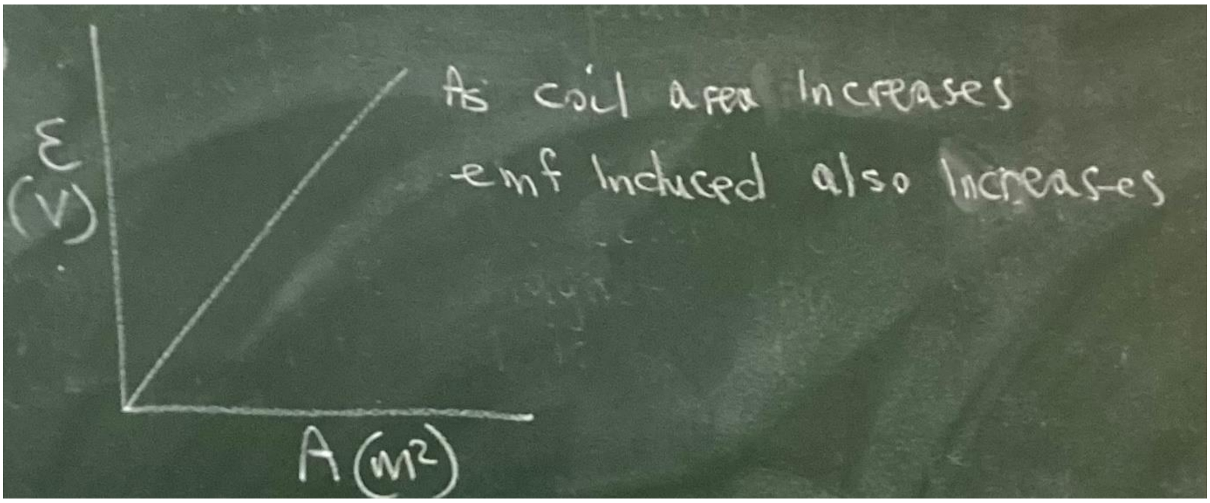


Figure 40: Snapshot showing graph used to explain the relationship between emf and cross-sectional area of the loop.

TE4: *As you can see from this graph that, an increase in cross-sectional area of the loop will consequently result in an increase in induced emf. Again, there exists a linear relationship between cross-sectional area and induced emf.*

The teacher proceeds to present yet another graph as shown in figure 41

TE4*: Now, we might also want to know what happens to the induced emf when the speed of coil rotation is varied.*

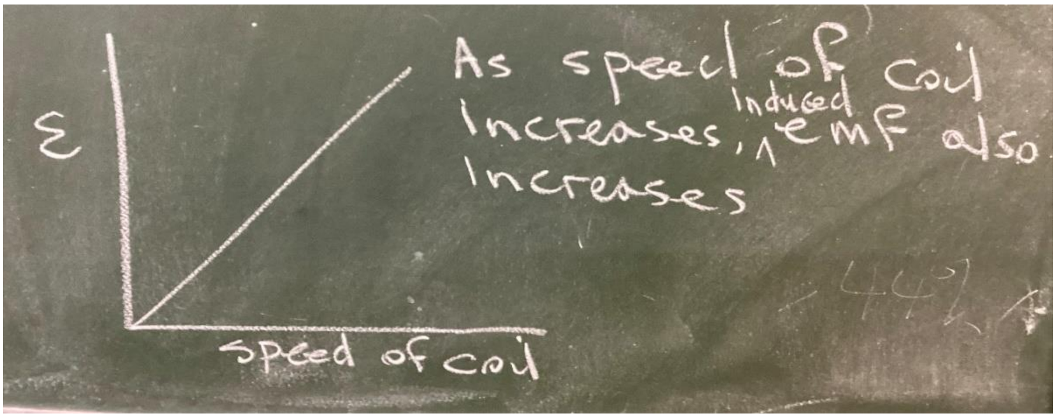
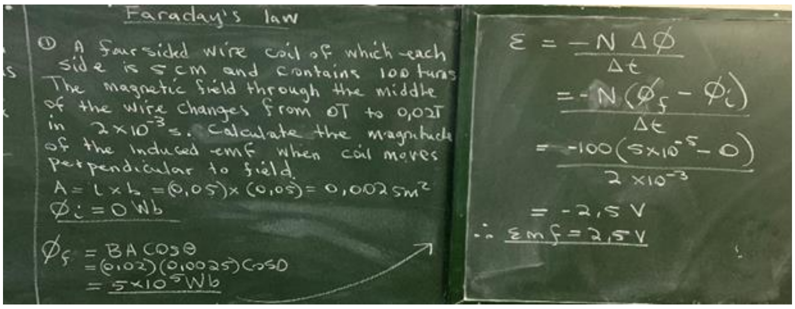


Figure 42: Snapshot showing graph used to explain the relationship between emf and speed of coil rotation.

TE4: *I hope you can all see from this graph that, an increase in speed of coil rotation in the magnetic field will consequently result in an increase in induced emf. Again, there exists a linear relationship between the speed of the coil and the induced emf.*

The teacher went on to give learners an example on the chalkboard of a numerical calculation based on Faraday`s formula as shown in figure 43.

TE4: *Now let us go through one or two examples together related to how we can perform calculations using Faraday`s law.*



Faraday's law

① A four sided wire coil of which each side is 5 cm and contains 100 turns The magnetic field through the middle of the wire changes from 0T to 0,02T in 2×10^{-3} s. Calculate the magnitude of the induced emf when coil moves perpendicular to field.

$A = l \times b = (0,05) \times (0,05) = 0,0025 m^2$

$\phi_i = 0 Wb$

$\phi_f = BA \cos\theta$

$= (0,02)(0,0025)\cos 0$

$= 5 \times 10^{-5} Wb$

$$\varepsilon = -N \frac{\Delta\phi}{\Delta t}$$

$$= -N \frac{(\phi_f - \phi_i)}{\Delta t}$$

$$= \frac{-100(5 \times 10^{-5} - 0)}{2 \times 10^{-3}}$$

$$= -2,5 V$$

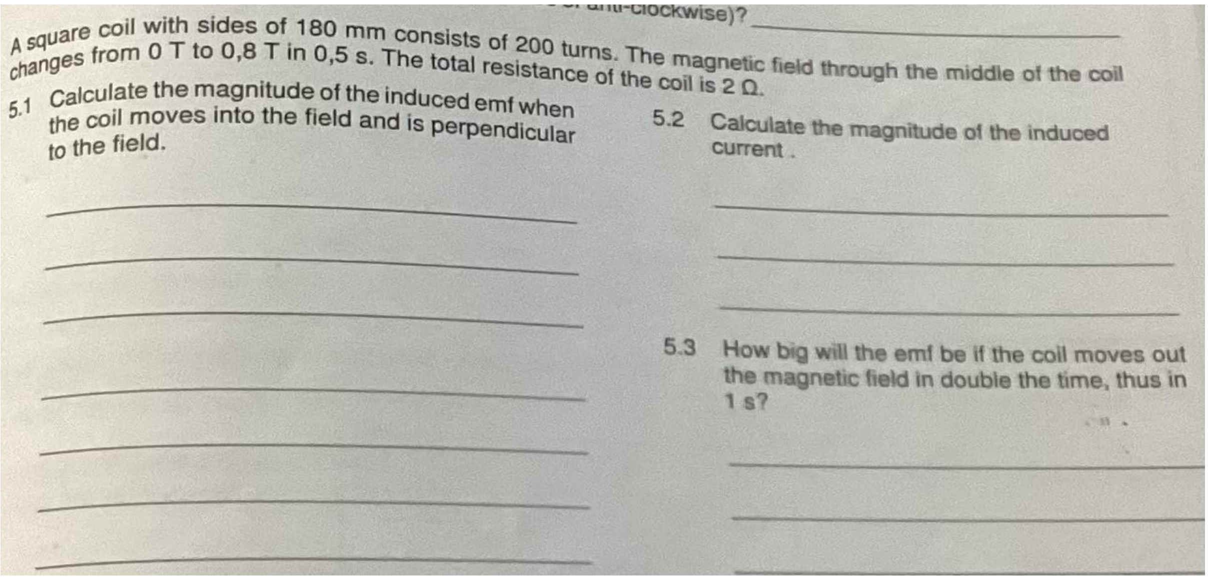
$\therefore$ emf = 2,5 V

Figure 43: Snapshot showing a chalkboard example of calculation based on Faraday`s formula.

TE4: *Please note that it is of paramount importance for us to first calculate the change in magnetic flux which also forms the numerator part of Faraday`s formula. And I think you can all realise that our final solution to the numerical problem on the chalkboard has a negative sign. So, in this case we ignore it and eventually present it as shown on the chalkboard. This is because our interest is only based on the magnitude of the induced emf. Any questions so far?*

The teacher then goes on to give them some practice questions as shown in figure 44.

TE4: *Can you please attempt question number 5 in your worksheet as an individual Answer the question into your classwork books.*



anti-clockwise)? ____

A square coil with sides of 180 mm consists of 200 turns. The magnetic field through the middle of the coil changes from 0 T to 0,8 T in 0,5 s. The total resistance of the coil is 2 Ω.

5.1 Calculate the magnitude of the induced emf when the coil moves into the field and is perpendicular to the field.

5.2 Calculate the magnitude of the induced current .

5.3 How big will the emf be if the coil moves out the magnetic field in double the time, thus in 1 s?

Figure 44: Snapshot showing a question given to learners as individual class activity based on FL

While the learners were busy with the question that she had assigned them to do, she moved around checking whether they were doing it right. She also came to realise that most of her learners were having a challenge with 5.2 part of the question.

TE4: *Excuse me class. I can see that most of you are facing a challenge on 5.2 which requires you to calculate the magnitude of the induced current. Let me write the relevant formula for you on the chalkboard. Here in 5.2, we make use of this formula which is associated with Ohm`s law. So, since we are given resistance and we have just calculated the magnitude of the induced emf, it's easy to determine the size of the induced current.*

Section 4: Conclusion [4mins 17s]

TE4: *I think you have all managed to attempt the questions which I gave you based on electromagnetic induction. Okay. I would like to also emphasise on the fact that Faraday`s law is very very important since we apply the principle of electromagnetic induction when generating electricity at our major electricity generators in SA. Please go through everything we have done so far since I am going to be giving you a test soon. I would like you to each answer questions 6, 7, 8, 9, and 10 as your homework in your classwork books.*

APPENDIX E1: TE1`S VSRI SESSION

The VSRI session was held at TE1`s school two days after conducting video recorded lesson observations. The responses given by the teacher gave the researcher an idea about the intrinsic nature and level of development of her personal PCK and, how the teacher justifies her enacted PCK based on available video recorded evidence. In this section the researcher presents some of the questions which were posed to TE1 during the VSRI session and how she responded to them. The following is a detailed narrative account of what transpired during TE1`s VSRI session

Researcher: **What is your general impression about the entire video clip which is based on your teaching of EMI specifically to your own learners?**

TE1: *Wow! The video was quite clear. But from the back of the class the EMI information which I wrote on the chalkboard is not visible. Maybe it's because the camera was positioned too far and at the back of our large class.*

I think my introduction is ok because I started off by linking the lesson on EMI and magnetic flux to the previous lesson which was based on magnetic field around a coil-carrying current. I then went on to introduce the concept of electromagnetic induction and Faraday`s law. I was also able to demonstrate Faraday`s law of EMI via simulation methods by making use of my own personal resources, I mean my laptop. I prepared a lot of handouts for my learners to enable me to save time writing and drawing diagrams on the chalkboard. Then afterwards i did some examples of how to perform calculations using the mathematical formulations of magnetic flux and Faraday`s law. Although it was weird to video-record my lesson while wearing our face masks, but what can we do since it has now become mandatory to put on face masks in public space.

Researcher: **Did you manage to achieve what you had planned in line with the post intervention CoRe?**

TE1: *Yes, I think I did manage to achieve the objectives of my lesson by trying to follow the outline presented in the post intervention CoRe tool. I also thoroughly prepared for this lesson. I would like to attribute the success of my lesson to your research intervention. I was able to treat both magnetic flux and EMI in just one lesson thus, leaving me in a much comfortable position in terms of ATP content coverage. In the past few years during my teaching practice as a pre-service teacher, I used to struggle presenting a lesson especially based on Faraday`s law but this time around it was much better.*

Researcher: **So, based on the evidence from this video recording, which areas were you strong at while teaching the EMI section?**

TE1: *All sections. I managed to cover everything about magnetic flux and EMI in line with the annual teaching plan. Most of my learners were also able to respond to the questions in the worksheet that I gave them and also during simulations at the end. I managed to guide my learners through the topic by asking appropriate questions relevant to the topic. I managed to successfully demonstrate induction by making use of a simulation approach. I also managed to explain the relevance of Faraday`s law to the generation of electricity.*

Researcher: **Which areas still need your serious attention next time should you be accorded with the chance to re-teach this section of EMI?**

TE1: *I think, I may need to give a bit of attention to my representations that I use in the topic of EMI. I think next time I will explore the use of real experiments with strong permanent bar magnets, coils of copper and a sensitive galvanometer. Or explore the use of some pre-selected YouTube videos when teaching a physics section such as EMI. I may also need to improve on translating my planned lesson into reality.*

Researcher: **What's your response to the following utterances which your made during EMI lesson presentation?**

VPB-1"……*Which means that our emf is induced only when the magnet makes a movement into or out of the coil*"

TE1: *Mmmmmmh of course! Or is it not correct to say that only the coil is stationary and it's the magnet which should move into or out of the coil? I guess you are not trying to suggest for me relative motion of coil and magnet. Ohh my…! It's true that is the meaning of relative motion. I messed up. I will have to address that again.*

VPB-2 *"………..`**B**` represents magnetic field strength measured in tesla (T) and, mean almost the same as magnetic flux. ….."*

TE1: *That is how I always perceive it. I guess I must change the perception I have for magnetic flux and magnetic field strength. I also must revisit my archives that I am using as my physics resource base.*

VPB-3 "……*something associated with what we call Lenz`s law and it's not in your syllabus. We cannot waste our time on something that will never be examined."*

TE1: *Even though the learner might have asked a relevant question, but there was no need for me to entertain the question in the presence of other learners. The explanation might see me dragging the lesson and eventually being left behind the pacesetter. That is why I requested the learner to see me as an individual for further clarity on Lenz`s law.*

Researcher**: Did you go through the CAPS document to check and see what you are expected to teach and what learners are expected to know in the section of electromagnetic induction?**

TE1: *Yes: I did go through the CAPS document, and I didn't see where I'm expected to teach about Lenz`s law. Not unless if there might be a hidden statement representing Lenz`s law. But I don't think so.*

Researcher: **Were you satisfied with your EMI representation method?**

TE1: *Not exactly. In this era covid-19 strict health protocols which also include maintaining social and physical distance of approximately 1.5m is to be strictly adhered to. At least i should have conducted the computer simulations in the computer centre because there is an overhead projector, but unfortunately the centre is under full utilisation by computer application & technology (CAT) learners. That is why I resorted to using my personal laptop in class so that at least my learners could be exposed to the reality of EMI and Faraday`s law. Here I only used simulations with my laptop to demonstrate to my learners Faraday`s law of electromagnetic induction. I wanted them to at least be exposed to the correct physics of how an emf is induced in accordance with Faraday`s law. It's unfortunate that our school laboratory is poorly resourced. I was at least supposed to experimentally demonstrate EMI to my learners. I am also thinking of exploring the use of pre-selected YouTube videos as a teaching method next time to represent EMI.*

Researcher: **What is your personal impression regarding video recorded lesson observations?**

TE1: *I personally think that teachers should video record their lessons and playback the videos to identify their areas of weaknesses and strength. This in the long run might promote the much-needed continued professional growth. Video recorded lesson observations also provide us with evidence of what transpired in the classroom. A VSRI also exposes your strength and weaknesses. As a physics teacher you can only professionally grow if you acknowledge your weaknesses. I hope that one day the department of basic education in SA will accept and adopt video recordings as means of lesson observations.*

APPENDIX E2: TE2`S VSRI SESSION

The VSRI session was held at TE2`s school a day after the video recorded lesson observations had been concluded. During the VSRI session he was given the chance to reflect on the lesson while referring to the playback from video recordings. Furthermore, the VSRI session accorded the teacher an opportunity to justify some of his actions during PCK enactment.

Researcher: **What is your general impression about the entire video clip which is based on your teaching of EMI specifically to your own learners?**

TE2: *The video was quite clear. Imagine a video being so visible after being captured from the back of the class. Even the diagrams I draw on the white board to illustrate the concept of electromagnetic induction were very clear. Although I initially had thought that the camera was positioned too far but the information on the board is clear. In my introduction, I started by reflecting on the previous lesson which was based on magnetic effect of a coil carrying current. This was important to enable the learners to grasp the link with the EMI concept. I then went on to treat the concept of magnetic flux first before dealing with electromagnetic induction and Faraday`s law. I was also able to clearly demonstrate Faraday`s law of EMI using PhET simulations methods. This of course was the most exciting part as you can see from the level of alertness and participation by learners. I then went on to treat some examples of how to perform numerical calculations based on the mathematical formulations of magnetic flux and Faraday`s law. Although we had no choice but to video-record the lesson while everyone was wearing face masks, but under COVID-19 health and safety protocols, we all have to comply and wear our face masks especially when in public space.*

Researcher: **Did you manage to achieve what you had planned in line with the post intervention CoRe?**

TE2: *I would like to think that I achieved more than what I had set out to achieve in both my lesson preparation and content representation tool which you gave me. I manged to cover the magnetic flux and Faraday`s law in this lesson. I was also able to administer some class activities and present PhET simulations based on EMI concept as was outlined in my post intervention CoRes. The use of PhET simulations also assisted in uprooting any possible misconceptions from learners. I was also able to respond to all questions and concerns from my learners with regard to the EMI topic. The use of the post CoRe tool contributed to the success of my EMI lesson as it resulted in a thoroughly prepared for this lesson. All thanks to your research intervention.*

Researcher: **So, based on the evidence from this video recording, which areas were you strong at while teaching the EMI section?**

TE2*: In as far as the CAPS syllabus is concerned, I am sure about having properly addressed most of the concepts that learners are expected to know as far as EMI is concerned. In the first place when you want the learners to fully understand Faraday`s law of electromagnetic induction, you need to address the concept of the magnetic flux. The learners also need to know how the flux changes, especially when the coil rotates. Once that is understood, it becomes quite easy to introduce Faraday`s law of electromagnetic induction. From Faraday`s law, learners are supposed to realise that the induced emf is directly proportional to the rate of change of magnetic flux. It is also important that we show learners experimentally how emf ends up being induced. However, in the absence of laboratory equipment, we can still show the simulations to the learners. I am glad because that is exactly how I presented it as shown in this video.*

Researcher: **Why he did you opt to also include grade 10 magnetism in your introduction to the big idea of magnetic flux?**

TE2*: I wanted my learners to realise that the section of magnetism is a prerequisite to their understanding of the magnetic flux and to also uproot any possible misconception which might be in their possession before we unpack the concept of magnetic flux. Remember, for learners to have a clear mental picture of the magnetic flux, first and foremost I wanted to remind them magnetic field strength before introducing magnetic flux. The reason being that flux focus mainly on magnetic field strength or field density through a loop of a specific cross-sectional area. My intention was to check whether the learners had some alternative conceptions related to magnetism before I introduce the concept of magnetic flux to them. As you know learners tend to demonstrate poor understanding of the domain theory. That is why they end up presuming that magnetic field lines originate from the north pole and terminate at the south pole.*

Researcher: **Which areas still need your serious attention next time should you be accorded with the chance to re-teach this section of EMI?**

TE2: *I think, I may need to give more attention to representation methods that I use in the topic of EMI. I think next time I will explore the use of both simulations and actual experiments with strong permanent bar magnets, coils of copper and a sensitive galvanometer. There is also need to explore the use of some pre-selected YouTube videos when teaching this section of electromagnetic induction to learners.*

Researcher: **Are you satisfied with the conceptual teaching strategy that you employed while treating this section with your learners?**

TE2: *When teaching concepts like magnetic flux and electromagnetic induction, there is need to have a set of guiding questions which are to be asked to learners just to be satisfied that you are moving at the same wavelength with them. Sometimes it's important that you don't just explain as if you are preaching to them. Physics is not approached like religion. Learners are also at liberty to ask questions at any stage during lesson execution. Teacher also needs to present some guiding questions to ensure better conceptualisation. It is quite apparent that learners grasp the conceptual differences especially between magnetic flux and magnetic field strength, magnetic flux and magnetic flux change and physical significance of the angle. This is because all these are pre-concepts central to their understanding of electromagnetic induction.*

Researcher: **What is your comment on the kind of questions in terms of their cognitive level which you asked learners during your lesson? In other words, are you satisfied with the kind of questions which you asked as part of your CTS?**

The kind of questions I asked were quite relevant. In fact, most of my questions especially during simulation presentation provoked higher order kind of thinking. For instance, one such question was related to `how the direction of induced current can be predicted. While the other question was related to why the galvanometer deflects in the opposite direction to the direction of the magnet.

Researcher: **How did you address the challenges of misconceptions associated with magnetic flux?**

TE2: *I started by reflecting on grade 10 magnetism. My intention was to check whether the learners had some alternative conceptions related to magnetism before I introduce the concept of magnetic flux to them. As you know learners tend to demonstrate poor understanding of the domain theory. That is why they end up presuming that magnetic field lines originate from the north pole and terminate at the south pole.*

Researcher: **Before introducing Faraday`s law you started off by recapping the right-hand rule and magnetic flux. Can you perhaps justify your strategy as to why you did it that way?**

The only way I can make my learners to understand Faraday`s law of electromagnetic induction is to make sure that they understand the application of the right-hand rule since it is needed to predict the direction of the induced current and consequently explain the physical significance of the negative sign in Faraday`s formula. This is because one of the causes of *misconceptions associated with Faraday`s law stems from learners` inability to account for the negative sign in the formula.*

Researcher: **What caused you not to separately simulate the big idea of magnetic flux. Was it not possible to demonstrate magnetic flux through simulations than combine it with EMI simulation?**

TE2: *Yes of course, it is very much possible. But in the interest of time, I decided to combine all magnetic flux simulations with EMI simulations. I didn't carry out a separate demonstration that was specifically focusing on the first big idea of magnetic flux. However, during the simulation experiments which were mainly centred on Faraday`s law, I did mention and further clarified the concept of magnetic flux. I realised that it was going to need more time to simulate magnetic flux and electromagnetic induction separately. So, I then decided to combine the simulation experiments together with the one related to Faraday`s law and electromagnetic induction and it worked.*

Researcher: **Were you satisfied with your EMI representation method?**

TE2: *To a greater extend I can say yes. I would have loved to represent the concept of electromagnetic induction principle experimentally. I think learners understand this electromagnetic induction concept better if they are given the opportunity to manipulate the apparatus and use them to explore induction principle directly. But in the absence of laboratory equipment the best available option will be to use simulations like I did.*

But maybe in future I may opt for some pre-selected YouTube videos as an additional representation method together with the PhET simulations when teaching EMI.

Researcher: **What is your personal impression regarding video recorded lesson observations?**

TE2: *It is indeed an effective way of promoting one`s professional growth since one would be able to critically observe and reflect on strength and weaknesses through use of video evidence of the lesson. Even though I have never video recorded my lessons while teaching, I only came to realise their effectiveness on lesson reflection after your intervention. It's a great idea which can also help to induct especially newly qualified teachers. For experienced teachers, it saves to provide room for improvement in teaching strategy for a specific topic. It also allows one to acknowledge his/her weaknesses and strength. Most importantly, it provides convincing evidence of how a lesson based on a specific topic was actually executed. I for one think that video recorded lesson observations is something which our provincial government should opt to adopt in our schools.*

APPENDIX E3: TE3`S VSRI SESSION

The VSRI session was held at TE3`s school a day after the video recorded lesson observations had been concluded. During the VSRI session he was given the chance to reflect on the lesson while referring to the playback from video recordings. Furthermore, the VSRI session accorded the teacher an opportunity to justify some of his actions during PCK enactment.

Researcher: **What is your general impression about the entire video clip which is based on your teaching of EMI specifically to your own learners?**

TE3*:* *I think the video was good. Because I was able to achieve my intended objectives as set in my lesson preparation book which of course was aided by the post intervention CoRe tool. Anyone can see that the video recorded lesson was based on Faraday`s law of electromagnetic induction. I was actually able to treat both sections of magnetic flux and Faraday`s law in one lesson. I started by reflecting on the previous lesson which was based on electric field around a straight conductor and solenoid carrying current. I also reflected on the application of the right-hand rule.*

I then went on to introduce the concept of magnetic flux and, also explained the difference between magnetic field strength and magnetic flux. I then gave some worked examples on the chalkboard on how to calculate the magnetic flux. After that i gave my learners some questions on the chalkboard to do as classwork. This actually assisted me to check and see if the learners had properly understood the concept of magnetic flux and the associated calculations

I then went on to introduce the concept of electromagnetic induction and Faraday`s law while linking it with magnetic flux. I also presented the mathematical formulations of Faraday`s law on the chalkboard and, thoroughly explained the physical significance of each symbol. As a form of representation, I decided to use graphical approach because learners can easily conceptualise the relationship between specific physical quantities. Although I would have loved to experimentally demonstrate the induction principle, but I couldn't. due to lack of functional laboratory resources. So instead, I decided to expose my learners to some apparatus used to demonstrate EMI. I also gave them a worked example based on numerical calculations before giving them some questions to attempt as individuals in their classwork books. I then concluded the lesson by mentioning the application of EMI in electric generators.

Researcher: **Did you manage to achieve what you had planned in line with the post intervention CoRe?**

TE3: *Yes, I am absolutely sure that I managed to address all the bullets specified in the CAPS document. I also did my best to follow the outline presented in the post intervention CoRe tool which you gave us. I was able to treat both magnetic flux and Faraday`s law in just one lesson which is fine in terms of ATP content coverage.*

Researcher: **So, based on the evidence from this video recording, which areas were you strong at while teaching the EMI section?**

TE3: *In as far as my understanding of Faraday`s law is concerned, I don't have a section where I can doubt myself. I may not be sure of whether my learners understood my explanations and my new approach when teaching this section of electromagnetic induction. I say new approach because this time I was being guided by the post intervention CoRe tool. I also blended my verbal explanations with some simulated videos as part of my conceptual teaching strategies. And I think my learners were left better equipped with knowledge of electromagnetic induction. But the impact on learner performance of this CoRe approach shall only be felt after the assessment.*

Researcher: **Which areas still need your serious attention next time should you be accorded with the chance to re-teach this section of EMI?**

TE3: *As a science teacher, I don't feel like I have done adequately without conducting some experiments. I think next time, I really need to give maximum attention to my representation methods that I use when treating the second big idea of Faraday`s law. In this era of technological advancement, I shall also explore the use of virtual labs or even some YouTube videos when teaching a physics section such as EMI.*

What are your personal views pertaining the idea of teachers having to video record their lessons?

I have fallen in love with video recorded lesson. It's an evidence-based lesson. The easiest way I can be able to reflect on my lesson without being biased is only if I can video record it and then do the playback. I will also be quickly able to observe my areas of strength and weaknesses.

Researcher: **Are you satisfied with the conceptual teaching strategy that you employed while treating this section with your learners?**

TE3: *Although my conceptual teaching strategy shown in this video may not necessary be exceptional or outstanding, but I actually did the best that any Physics teacher could have done. I mean the way I explained the concept of magnetic flux and how its related to Faraday`s law and, the guiding questions which I paused to learners as well as the way I addressed any* *possible misconceptions held by learners in this section of electromagnetism. I also used simulations of videos to aid my verbal explanations and it worked very well. I think I did it in a satisfactory manner.*

Researcher: **Were you satisfied with your EMI representation method?**

TE3: *Not exactly. My representation lacked experiments. I did not cooperate the experimental aspect which is of great importance especially to confront possible misconceptions held by learners. Just mere explanations of concepts accompanied with video simulations were not enough as learners tend to either easily forget or misrepresent Physics at a later stage. At least I should have maybe tried using some real practical demonstration especially when treating the concept of electromagnetic induction.*

Researcher: **Can you please justify your approach of introducing a topic such as EMI with a video.**

TE3: *The short video was just a brief summary of the two big ideas, and it was meant to give my learners the overall impression of what to expect in the lesson. It is important for me to try and make my learners to stay alert and motivated from the beginning till the end. From my few experiences in teaching, I have noted that most learners love lessons blended with videos. It is important for me to try and make my learners to stay alert and motivated from the beginning till the end. From my few experiences in teaching, I have noted that most learners love lessons blended with videos.*

Researcher: **How come you opted to explain the concept of magnetic flux using chalkboard without being aided by some experiments, or video simulations?**

TE3: *I have personally never been able to witness an experiment based on magnetic flux. Therefore, I thought there was no need to even to think about video simulations based on magnetic flux only. However, the video simulations based on Faraday`s law could also be used to emphasise on magnetic flux like I did at last. There is no way I could have independently represented a video simulation based only on the flux concept without involving Faraday’s law of electromagnetic induction. That is why I had to also reiterate the flux concept during my video simulation presentation to the class.*

Researcher: **Why did you opt to introduce the big idea of Faraday`s law with a video?**

TE3: *I wanted my learners to have a complete picture of electromagnetic induction as well as an overall impression about Faraday`s law. I also used the video as a motivational tool to capture their attention. It’s just unfortunate that these were the only apparatus that I had.*

Researcher: **How do you justify your approach of having used dysfunctional equipment for demonstration EMI? Did you do some pre-trial experiment before the lesson?**

TE3: *It might be that the magnet was too weak to cause any deflection or the ammeter itself was having a problem. I suppose, I should have started by testing the equipment before bringing them to class. But anyway, at least I exposed the learners to the actual apparatus and also showed them how to connect them. Besides, I wanted to expose my learners to the laboratory apparatus used in real experiment of electromagnetic induction, and also enable them to have the correct mental of how induction is practically conducted. It's also a working strategy I used to capture their attention.*

Researcher: **Why should learners not use any angle provided to them when performing calculations using flux formula?**

TE3: *Some learners tend to develop some misconception related to the angle. Sometimes questions are presented in such a way that learners must figure out or even calculate the angle between normal line and the field. So, if learners just use any angle given to them, they will end up being trapped by some questions. The calculations become difficult especially if the angle is mis-interpreted or incorrectly determined.*

Researcher: **You mentioned the rate of change in magnetic flux and relative motion between coil and magnet during and after introducing Faraday's law. Can you justify your approach.**

TE3: *While it's a noble idea to expose learners to the physics of relative motion and rate of change in magnetic flux, but the explanation is more vivid when contextually dealing with Faraday's law.*

Researcher: **What is your personal impression regarding video recorded lesson observations?**

TE3: Video recorded lesson observations are good. Actually, this method brings transparency during lesson execution. It makes teachers to be honest and to constructively criticise themselves after the lesson. You don't need anyone to inform you of your loopholes. Video recorded lesson observations can even be adopted by school management teams (SMTs) when monitoring teachers at school level. With a video recorded lesson you can freely discuss the aftermath lesson with a teacher without him or her feeling offended at the end. *I personally think that teachers should video record their lessons and playback the videos to reflect on their weaknesses and strength. This also promotes the ethics of the much-needed continued professional growth.*

APPENDIX E4: TE4`S VSRI SESSION

The VSRI session was held at TE4`s school two days after conducting video recorded lesson observations. The responses given by the teacher gave the researcher an idea about the intrinsic nature and level of development of her personal PCK and, how the teacher justifies her enacted PCK based on available video recorded evidence. In this section the researcher presents some of the questions which were posed to the in-service teacher TE4 during the VSRI session and how she responded to them. The following is a detailed narrative account of what transpired during TE4`s VSRI session

Researcher: **What is your general impression about the entire video clip which is based on your teaching of EMI specifically to your own learners?**

TE4: *I think I tried my best to present the lesson based on magnetic flux and Faraday`s law. This was my first time to be teaching this section to the grade 11s. I managed to explain to them what magnetic flux is and how it is linked to change in magnetic flux and Faraday`s law. I also explained the meaning of all the symbols that are used in both formulas for flux and for Faraday's law. I also gave them typical examination questions as examples as well as classwork activities. I actually treated all the bullets as expected by both the examination guidelines and CAPS syllabus.*

Researcher: Can **you justify yourself for the teaching strategy which you used in this lesson to treat electromagnetism?**

TE4: *Like I once indicated to you earlier on that it was actually my first time to be teaching a grade 11 physical sciences class and later on the section of electromagnetic induction. After such a great exposure, I am hoping to develop better conceptual teaching strategies with time.*

Researcher: In your CoRes you indicated that you shall conduct experiment. What challenges did you face which led you to deviate from your conceptual teaching strategies and representations as suggested in your post-CoRe?

TE4*: Yes, I actually thought that I was going to be able to conduct the experiment to demonstrate the concept of magnetic flux and Faraday`s law. But I only realised when I was about to begin with this section that we don't have the necessary laboratory equipment even for a simple demonstration. I even tried to borrow some lab equipment related to this section from my neighbouring school. But the teacher was unable to give me since she was also busy with the same section with her learners. That is why I ended up doing it this way.*

Besides, that I can't still imagine how such an experiment to demonstrate magnetic flux can be done even if we had equipment. Simulations are perhaps possible but unfortunately, I don't have any simulations or videos related to this entire section of EMI in my laptop.

Researcher: **Based on evidence from this video playback, do you think you managed to achieve what you had planned?**

TE4: *I think I did my best, even the graphs that I have use to assist learners in understanding the concept of the flux were quite relevant. I also went through an example with them which I presented on the chalkboard. I then gave them some questions to attempt as individuals based on the example and they did very well.*

Researcher: **So, based on the evidence from this video recording, which areas were you strong at while teaching the EMI section?**

TE4: *let me say most of the areas except when it comes to accounting for the negative sign presented in Faraday`s law. I managed to treat and explain the physics of magnetic flux and electromagnetic induction to my learners in line with the revised exam guidelines. Also, a lot more of graphical work. Many of my learners were also able to actively participate during my presentation on electromagnetic induction as you can see from the video. Most of their responses to the questions I paused during class discussions were an indication that they were also paying attention and hence they were understanding me as I explained. I also managed to explain and assess them on magnetic flux and Faraday`s law. By assessment I am referring to the classwork I gave them in which most of them responded well.*

Researcher: **Which areas still need your serious attention next time should you be accorded with the chance to re-teach this section of EMI?**

TE4: *I think my conceptual teaching strategies were very poor as well as their associated representations. I should have done much better by perhaps blending my explanations of concepts with simulations or videos from the internet. I wanted to quickly cover this section of the annual teaching plan but at the expense of my learners.*

During the VSRI session that the teacher first acknowledged her lack of understanding of some certain concepts as discussed below.

For instance, in the video play back (VPB) of the lesson, the teacher was quoted saying:

VPB-1"…*I think you can see a negative sign in the formula. This is the only formula I know of in physics which has a negative sign in it. So please when using this formula, don't forget that there is a negative sign.*

However, when one of her learners questioned about the origin of the negative sign in Faraday`s formula, no convincing explanation was given by the teacher.

VPB-2 *Don’t worry much about the negative sign. But always remember to include it when calculating that there is a negative sign.*

Researcher: **What’s your response to such utterances which your made during EMI lesson presentation?**

TE4: *Honestly speaking I didn’t know what to tell my learners about the negative sign, but I had to say something. I prayed that no one asks about the origin of the negative sign but unfortunately one of my learners ended up asking.*

Another learner from her class requested to assist in giving an explanation pertaining the negative sign

VPB-3 …..*I think the negative sign has to do with the direction of the induced current which can also be predicted by using Lenz`s law.*

Researcher: **What is your comment based on the responses from one of your learners during the lesson based on Faraday`s law**

TE4: *That was a blessing in disguise. I felt so relieved, and I had to acknowledge that learner`s explanation which I also needed the most and that is why I even requested the class to clap hands for him.*

Researcher: **Were you satisfied with the teaching strategies which you employed while teaching both magnetic flux and Faraday`s law.**

TE4: *Not at all. I think that is where I could have done better by perhaps doing a simple demonstration based on electromagnetic induction. But due to the lack of necessary laboratory apparatus, doing a demonstration was not possible. Maybe perhaps I could have used my own personal laptop to show some simulations or simulated videos related to magnetic flux and Faraday`s law. Unfortunately, I don’t have any videos or simulations related to the entire section of electromagnetism.*

Researcher: **What is the stance of CAPS syllabus pertaining the direction of induced current?**

TE4: *Yes, in the CAPS document, there is a bullet about direction of the induced current. I have always been wondering to myself how this could possibly be done. But I now understand what that bullet was implying. But at least it could have easily been interpreted if they had explicitly stated it as Lenz`s law.*

Researcher: **In this video there is no evidence of any attempt to draw a diagram to at least assist the learners in terms of the angle. What do you have to say about your approach?**

TE4: *I am not that good in terms of drawing. Besides that, I thought that the learners would visualise the angle from the handouts which we used while dealing with the questions.*

Researcher: **Were you satisfied with your EMI representation method?**

TE4: I would have preferred to at least experimentally expose my learners to the correct physics of how an emf is induced in accordance with Faraday`s law. Unfortunately, our school laboratory is poorly resourced. In fact, it is barely empty. I am really not satisfied with my representation methods that I have just used while treating the topic of electromagnetic induction. Representation methods like simulations or preselected YouTube videos may greatly assist not only in complementing the lack of adequate laboratory equipment, but also in circumventing misconceptions especially related to Lenz`s law. I will adopt such representation methods next time. I don’t like the representation methods of just using chalkboard and duster as shown in this video. To me this is not good at all.

Researcher: **What is your personal impression regarding video recorded lesson observations?**

TE4: *It is quite imperative for me as an educator to video record and play back my lessons. This provides me with quick evidence-based way of reflecting on my lesson. this will further assist me to grow professionally as I will be able to develop better teaching strategies. It allows our teaching approaches as physical science teachers to develop gradually and professionally as long as we acknowledge our weaknesses and strengths.*

APPENDIX F1: TE1`S SEMI-STRUCTURED INTERVIEW RESPONSES.

An SSI session was conveniently carried out at teacher TE1's school and in the comfort of her office, after school hours to avoid disrupting her lessons and other school programmes. The SSI session was carried out three days after the video-recorded EMI lesson observation. The teacher responded to all the questions asked during the session. The entire SSI session which was audio-recorded through the teacher's permission lasted for approximately thirty-four minutes.

Researcher: **Are you currently registered for any further studies? Importance of EMI to the learner in daily life. Was the learner`s prior knowledge adequately covered.**

TE1: *No. I am not registered for any further studies. I am already fast approaching my retirement age. I wouldn't want at my age to stress myself with any academic staff.*

Researcher: **Have you previously participated in any Physical Sciences continued professional development training program/workshop before?**

TE1: *Yes of course, Throughout my career as a high school physical sciences teacher a I have attended several workshops and conferences most of which were related to face-lifting teachers` content gaps in many areas of physics and chemistry. For instance, here in SA after the end of year final national senior certificate (NSC) examinations, we always receive a diagnostic report from the DBE examination section detailing the challenges which learners faced per every topic that was examined. It is such topics that we discuss in our workshops as part of continued professional growth.*

Researcher: **Could you tell me about your background in EMI and teaching of EMI?**

TE1: *Its quite an interesting field of study with a lot of good if not advanced mathematics. I remember during my days while doing honours in physics we used to brag about Maxwellian equations in EMI. Faraday`s law being part of the so-called Maxwell`s equations, can be represented in integral and differential form. I have always enjoyed the section of electromagnetism. Although teaching is not that easy because explaining high order concepts of magnetic flux, vectorial nature of magnetic field to learners with poor mathematical background and ill-resourced school is an uphill task.*

Researcher: **What are your personal views about the training your received during this period of intervention? Do you think that such a training experience added any value to your teaching profession?**

TE1: *This intervention you brought to us was quite relevant and worth to be recommended to the DBE for adaption especially by physical sciences teachers. The use of the CoRe tool* *makes it easier and sounds orderly especially when tackling high order concepts such as EMI. If our low experienced and novice physics teachers can adopt CoRe tool as part of their lesson preparation I doubt if they will face a lot of challenges when it comes to content delivery. I totally agree that such an intervention is a perfect game changer especially in science teaching.*

Researcher: **What do you think makes the teaching and learning of EMI to be difficult for students? What makes it easy to teach?**

TE1: *Like I high-lighted earlier, EMI is a high order concept with strong mathematical background. Another point is that the imaginations to be taken into considerations when it comes to generation of an emf are far beyond the reach of most of our high school learners. That’s why there are also a lot of alternative conceptions by learners and even some teachers. Our CAPS syllabus does not allow us to provide more emphasis on Lenz`s law which is inevitable when teaching about EMI and Faraday`s law. Yet some of the alternative conceptions could be delt with by Lenz`s law. For instance, how would one as a teacher explain to the learners, the physical significance of the negative sign which pops up in the mathematical expression of Faraday` s law without emphasising on Lenz`s law? Besides that, we also have lack of adequate laboratory equipment in our rural schools even for demonstration purposes. Meaning that whatever we explain to the learners about EMI is what they will take, be it wrong or correct.*

Researcher: **Is the direction of current mentioned under EMI in the CAPS document?**

TE1: *I am not quite sure. Mmmmh but it stipulates that learners are expected to know the direction of induced current. Oh my…!, that is Lenz`s law. But they supposed to straight away talk about Lenz`s law instead of beating about the bush. I guess I should go through it again to see since I might have missed a lot of other things.*

Researcher: **What is it that you liked about the intervention? What did you learn about teaching EMI to the Grade 11 learners?**

TE1: *The idea that I learnt and which I am personally going to adopt from henceforth in my career is the use of what you call the CoRe tool components with my lesson preparation. It actually promotes smooth flow of ideas from teacher to learners. It also allows me as a teacher to do some introspection and professionally to realise where I may need help. The other main idea which I also appreciate of worth my consideration is video recording my lesson. It will assist me to see whether how I explained EMI concepts to the learners was correct or not.*

Researcher: **What is it that you did not like about the intervention?**

TE1: *There is nothing that I can say was not good about the intervention except that it came at a time when the country is in trouble due to COVID-19. Hence, a lot of health protocols and standardised operating procedures are to be strictly adhered to. This might have negatively impact on the expected outcome of such an intervention. I would also like to suggest that the CoRe tool be used to substitute the lesson preparation instead of the two being used concurrently to avoid much and unnecessary writing.*

Researcher: **Is there anything else which you wish to learn and know about EMI, teaching EMI and PCK for your continued professional growth? Any alternative conception that you have? Misconceptions from your learners and how to address them.**

TE1: *Nothing more. With my CoRe tool and video recorded lesson what else can I ask for? This intervention actually assisted me in identifying some misconception which I was having in this section of EMI and Faraday`s law. For instance, the issue of relative motion between coil and magnet, the issue of the difference between magnetic flux and magnetic field and obviously Lenz`s law.*

Researcher: **How do you usually teach EMI in your own way as an experienced teacher?**

TE1: *Before this intervention which you instituted, I used to just do my lesson preparation. Then after I would go to class and present the topic of electromagnetism. Sometimes I would even finish the entire section of electromagnetism without any demonstration or simulation except textbook information. In other circumstances, depending on the availability of time I may end up doing it for compliance`s sake, just to cover the pacesetter, I may just end up doing some demonstrations or simulations related to EMI.*

Researcher: **How would you go about teaching this topic or any other difficult topic in future?**

TE1: *Use my lesson preparation in conjunction with my content representation tool. I will video record any lesson with abstract concepts such as electromagnetism. From video playback I will be able to reflect on my lesson and compare what I had planned with how I actually did it. If need be, I will provide the necessary adjustments. Believe me, if I say I have learnt a lot especially about my teaching methods from VSRI based on the topic of grade 11 EMI. Video recording your lesson and then instituting a playback of it will assist you a lot in realising your loopholes. Once you realise that you can be able to implement necessary adjustments.*

Researcher: **To what extend does your approach to teaching topics such as EMI impact on your self-efficacy?**

TE1: *The way I approach the teaching of EMI save as a yardstick. Hence the way I teach it says a lot about me as a teacher. I usually use it as one of the topics that should defend my professional integrity as a physics teacher.*

Researcher: **How do you plan to assess or seek for the evidence that learners have successfully been able to address the goals of your lesson in the topic of EMI?**

TE1: *I normally give them an end of topic test with some few multiple-choice questions and one good long and free response questions in that test But, in this case after such an intervention your post-test based on EMI is the only assessment that they will receive. I am also going to record it.*

Researcher: **About the representation strategy. Which method of representation would you advice/share with other physics teachers to assist learners that might experience difficulties regarding understanding the topic of electromagnetism?**

TE1: *If a school`s laboratory system is adequately resourced; I would advocate for the experimental approach because hands on experience with apparatus will enable learners to concretise concepts. My opinion is based on the video stimulated recall interview session which I had earlier on with you. I noted with concern that not all of my learners could view EMI simulations from the back. That is why I would advocate for individual experiments at well-resourced schools especially during this era of COVID-19 pandemic. But if a school has adequate ICT facilities including overhead data projectors, then physics teachers should adopt simulations and videos as part of smart representation methods.*

APPENDX F2: TE2`S SEMI-STRUCTURED INTERVIEW RESPONSES.

An SSI session was conveniently carried out at teacher TE2's school and in the comfort of his office, after school hours to avoid disrupting his lessons and other school programmes. The SSI session was carried out three days after the video-recorded EMI lesson observation. The teacher responded to all the questions asked during the session. The entire SSI session which was audio-recorded through the teacher's permission lasted for approximately thirty minutes.

Researcher: **Are you currently registered for any further studies? Importance of EMI to the learner in daily life. Was the learner`s prior knowledge adequately covered.**

TE2: *No. I am not registered for any further studies. I am already fast approaching my retirement age. I wouldn't want at my age to stress myself with any academic staff.*

Researcher: **Which teaching strategies did you employ in order to ensure that learners understand EMI better?**

TE2: *I used the PhET simulations during my lesson on Faraday's to further reinforce the EMI concept to my learners. I should also have adopted the experimental approach if our school's laboratory was adequately resourced. However, in my case I had limited options.*

Researcher: **What are your reasons for not demonstrating the concept of magnetic flux experimentally or even through simulations**

TE2: *Yes, it is true. I could have done better in my conceptual teaching strategy and representations in line with magnetic flux. I think next time I need to improve on that aspect. Although I may seem to be justifying myself, but my verbal explanation was quite convincing. I could tell from their correct response to the class activity which I gave them.*

Researcher: **Have you previously participated in any Physical Sciences continued professional development training program/workshop before?**

TE2: *Yes of course, Throughout my career as a high school physical sciences teacher a I have attended several workshops and conferences most of which were related to face-lifting teachers` content gaps in many areas of physics and chemistry. For instance, here in SA after the end of year final national senior certificate (NSC) examinations, we always receive a diagnostic report from the DBE examination section detailing the challenges which learners faced per every topic that was examined. It is such topics that we discuss in our workshops as part of continued professional growth.*

Researcher: **Could you tell me about your background in EMI and teaching of EMI?**

TE2: *Its quite an interesting field of study with a lot of good if not advanced mathematics. I remember during my days while doing honours in physics we used to brag about Maxwellian equations in EMI. Faraday`s law being part of the so-called Maxwell`s equations, can be represented in integral and differential form. I have always enjoyed the section of electromagnetism. Although teaching is not that easy because explaining high order concepts of magnetic flux, vectorial nature of magnetic field to learners with poor mathematical background and ill-resourced school is an uphill task.*

Researcher: **What are your personal views about the training your received during this period of intervention? Do you think that such a training experience added any value to your teaching profession?**

TE2: *This intervention you brought to us was quite relevant and worth to be recommended to the DBE for adaption especially by physical sciences teachers. The use of the CoRe tool makes it easier and sounds orderly especially when tackling high order concepts such as EMI. If our low experienced and novice physics teachers can adopt CoRe tool as part of their lesson preparation I doubt if they will face a lot of challenges when it comes to content delivery. I totally agree that such an intervention is a perfect game changer especially in science teaching. I would like to acknowledge the way CoRes are presented. It makes it much easier to sail through the lesson especially if used in conjunction with lesson preparations and CAPS document.*

Researcher: **What do you think makes the teaching and learning of EMI to be difficult for students? What makes it easy to teach?**

TE2: *Like I high-lighted earlier, EMI is a high order concept with strong mathematical background. Another point is that the imaginations to be taken into considerations when it comes to generation of an emf are far beyond the reach of most of our high school learners. That's why there are also a lot of alternative conceptions by learners and even some teachers. Our CAPS syllabus does not allow us to provide more emphasis on Lenz`s law which is inevitable when teaching about EMI and Faraday`s law. Yet some of the alternative conceptions could be delt with by Lenz`s law. For instance, how would one as a teacher explain to the learners, the physical significance of the negative sign which pops up in the mathematical expression of Faraday` s law without emphasising on Lenz`s law? Besides that, we also have lack of adequate laboratory equipment in our rural schools even for demonstration purposes. Meaning that whatever we explain to the learners about EMI is what they will take, be it wrong or correct.* Both the big ideas of MF and FL require thorough preparation on the part of the teacher. *To understand the entire process of electricity generation, one needs to start off with the electromagnetic induction principle. However, my* *only concern is that such an abstract and important section in our modern lives of electricity generation has been made very short in the CAPS document. It is also accorded very few marks even in the examination guidelines.*

Researcher: **What is it that you liked about the intervention? What did you learn about teaching EMI to the Grade 11 learners?**

TE2: *The idea that I learnt and which I am personally going to adopt from henceforth in my career is the use of what you call the CoRe tool components with my lesson preparation. It actually promotes smooth flow of ideas from teacher to learners. It also allows me as a teacher to do some introspection and professionally to realise where I may need help. The other main idea which I also appreciate of worth my consideration is video recording my lesson. It will assist me to see whether how I explained EMI concepts to the learners was correct or not.*

Researcher: **What is it that you did not like about the intervention?**

TE2: *There is nothing that I can say was not good about the intervention except that it came at a time when the country is in trouble due to COVID-19. Hence, a lot of health protocols and standardised operating procedures are to be strictly adhered to. This might have negatively impact on the expected outcome of such an intervention. I would also like to suggest that the CoRe tool be used to substitute the lesson preparation instead of the two being used concurrently to avoid much and unnecessary writing.*

Researcher: **Is there anything else which you wish to learn and know about EMI, teaching EMI and PCK for your continued professional growth? Any alternative conception that you have? Misconceptions from your learners and how to address them.**

TE2: *Nothing more. With my CoRe tool and video recorded lesson what else can I ask for? This intervention actually assisted me in identifying some misconception which I was having in this section of EMI and Faraday`s law. For instance, the issue of relative motion between coil and magnet, the issue of the difference between magnetic flux and magnetic field and obviously Lenz`s law.*

Researcher: **How do you usually teach EMI in your own way as an experienced teacher?**

TE2: *Before this intervention which you instituted, I used to just do my lesson preparation. Then after I would go to class and present the topic of electromagnetism. Sometimes I would even finish the entire section of electromagnetism without any demonstration or simulation* *except textbook information. In other circumstances, depending on the availability of time I may end up doing it for compliance`s sake, just to cover the pacesetter, I may just end up doing some demonstrations or simulations related to EMI.*

Researcher: **How would you go about teaching this topic or any other difficult topic in future?**

TE2: *Use my lesson preparation in conjunction with my content representation tool. I will video record any lesson with abstract concepts such as electromagnetism. From video playback I will be able to reflect on my lesson and compare what I had planned with how I actually did it. If need be, I will provide the necessary adjustments. Believe me, if I say I have learnt a lot especially about my teaching methods from VSRI based on the topic of grade 11 EMI. Video recording your lesson and then instituting a playback of it will assist you a lot in realising your loopholes. Once you realise that you can be able to implement necessary adjustments. What is of paramount importance is for learners to understand that the rate at which magnetic flux changes is directly associated with the magnitude of emf output. Yes, it's not magnetic flux which determines emf output, but it's the rate at which the magnetic flux changes.*

I prefer to stress the importance of introducing magnetic flux through giving much emphasis of the learners' understanding of magnetic field strength. For instance, *the grade 10 physics of magnetism is of paramount importance since its prerequisite to learner's understanding of magnetic flux. Remember that you can only account for the magnetic flux by considering the amount of magnetic field density passing through a loop of cross-sectional area.*

Researcher: **To what extend does your approach to teaching topics such as EMI impact on your self-efficacy?**

TE2: *The way I approach the teaching of EMI save as a yardstick. Hence the way I teach it says a lot about me as a teacher. I usually use it as one of the topics that should defend my professional integrity as a physics teacher.*

Researcher: **How do you plan to assess or seek for the evidence that learners have successfully been able to address the goals of your lesson in the topic of EMI?**

TE2: *I normally give them an end of topic test with some few multiple-choice questions and one good long and free response questions in that test But, in this case after such an intervention your post-test based on EMI is the only assessment that they will receive. I am also going to record it.*

Researcher: **About the representation strategy. Which method of representation would you advice/share with other physics teachers to assist learners that might experience difficulties regarding understanding the topic of electromagnetism?**

TE2: There is interrelatedness between *Faraday's law and Lenz's law* and between *Lenz's law and the RHR* as challenges when teaching EMI. Hence, It is imperative that teachers make use of variable CTS when dealing with the concepts of MF and FL. Therefore, I strongly suggest the use of real experiments in conjunction with simulations and chalkboard diagrams as representations and part of the conceptual teaching strategies.

If a school`s laboratory system is adequately resourced; I would advocate for the experimental approach because hands on experience with apparatus will enable learners to concretise concepts. My opinion is based on the video stimulated recall interview session which I had earlier on with you. I noted with concern that not all of my learners could view EMI simulations from the back. That is why I would advocate for individual experiments at well-resourced schools especially during this era of COVID-19 pandemic. But if a school has adequate ICT facilities including overhead data projectors, then physics teachers should adopt simulations and videos as part of smart representation methods.

APPENDIX F3: TE3`S SEMI-STRUCTURED INTERVIEW RESPONSES.

An SSI session was conveniently carried out at TE3's school and in his office, after school hours to avoid disrupting his school-based programmes. The SSI session was carried out two days after the video-recorded EMI lesson observation. The entire SSI session lasted for thirty-one minutes.

Researcher: **Are you currently registered for any further studies?**

TE3: *Not yet. But I am still contemplating on registering for a BEd honours programme.*

Researcher: **Can you briefly tell me whether you managed to achieve the intended goals and objectives as suggested in your post intervention CoRe.**

TE3: Yes, i managed to address all the bullets about magnetic flux and Faraday's law as specified in the CAPS document. *I can also attribute this to my ability to follow what I had outlined in my post intervention CoRe. This made it possible for me to teach both magnetic flux and Faraday's law in just one lesson.*

Researcher: **Have you previously participated in any Physical Sciences continued professional development training program/workshop before?**

TE3: *Yeah. There are many workshops that I have attended so far as a qualified and experienced physical sciences teacher. Most of the workshops primarily focused on capacity building each other as colleagues. Where one teacher might be having a challenge about teaching a specific topic or section, we discuss at cluster level as to how best we can teach the concepts of a given topic. Our discussions also included but were not limited to misconceptions held by learners or even by teachers.*

Researcher: **Could you tell me about your background in EMI and teaching of EMI?**

TE3: *I can generally say that its fair. I have a good mathematical background and the in depth understanding of electromagnetism is hidden in the interpretation of mathematical physics. However, teaching of EMI versus knowing it is different. I'm one of the educators who always struggle to make learners understand this section by explaining it.*

Researcher: **What are your personal views about the training your received during this period of intervention? Do you think that such a training experience added any value to your teaching profession?**

TE3: *I really acknowledged the aspect of making use of the content representation tool prior to lesson execution. By so doing, you will be able to address all facets of an abstract concept such as EMI. Even the use of video recording your lesson and playing it back after will aid you* *in discovering your pedagogical shortfalls and strength. This will assist you in re-strategizing. Yeah, the impact was huge and positive.*

Researcher: **What do you think makes the teaching and learning of EMI to be difficult for learners?**

TE3: What he thought made the teaching and learning of EMI difficult for learners, I think ack of enough laboratory resources is a main cause as this makes teachers to end up relying on textbooks for explanations. *Learners come into Grade 11 with a lot of misconceptions related to grade 10 magnetism. Furthermore, this EMI section just like any other section in physics takes in a lot of imagination. The attribute of imagination is what tends to be lacking amongst most of our learners.*

Researcher: **What is it that you liked about the intervention? What did you learn about teaching EMI to the Grade 11 learners?**

TE3: *The completion of CoRe tool followed by video recorded lesson observation is a plausible approach especially treating tricky sections like EMI.*

Researcher: **What is it that you did not like about the intervention?**

TE3: *The high amount of writing involved in completing the content representation instrument as well as the normal lesson planning makes it unattractive. I wish if it can just replace what we call our daily lesson preparation. Because if you complete the CoRe tool and then go on to do lesson preparation, it becomes hectic.There was too much of writing involved in completing the post intervention content representation instrument.*

Researcher: **How would you go about teaching this topic or any other difficult topic in future?**

TE3: *To bring a facelift to my personal PCK, I will adopt the CoRe tool and video record my lessons as specified in this intervention.*

Researcher: **What kind of support, do you need to improve your teaching of electromagnetic induction?**

TE3: *I wish if I could get someone to assist me with videos or simulation videos based specifically on magnetic flux. Or if there is someone out there who might assist me with a practical way of demonstrating the existence of to the learners.*

Researcher: **Is there anything else which you wish to learn and know about EMI, teaching EMI and PCK for your continued professional growth?**

TE3: *To me there is nothing more since the use of the CoRe tool and video recorded lessons will positively impact on teacher`s PCK development*

Researcher: **How do you usually teach EMI in your own way as an experienced teacher?**

TE3: *I usually start off with a lesson preparation followed by lesson execution aided with prescribed textbooks. My school has very laboratory facilities and the issue of experimental approach is ruled out. So, I normally do the explanations of concepts while also writing some notes on the body.*

Researcher: **Would you please comment on your teaching strategies prior to intervention compared to your post-intervention strategies**

TE3: Yes, there was a noticeable difference. *Many of us teachers have fair amount of subject content knowledge, but the teaching methodology is a cause for concern. Hence, there is need for continued professional development. But once your methods of teaching are upgraded, the level of learner understanding of concepts will increase. I considered my methods of teaching to have been upgraded especially through the use of CoRes and also video stimulated recall.*

Researcher: **To what extend does your approach to teaching topics such as EMI impact on your self-efficacy?**

TE3: *To some extent, one`s self-efficacy will be compromised since thorough understanding of grade 11 EMI is a pre-requisite to the grade 12 topic of electrodynamics.*

Researcher: **How do you plan to assess or seek for the evidence that learners have successfully been able to address the goals of your lesson in the topic of EMI?**

TE3: *This time around I will make use of the researcher`s post-test based on electromagnetism. This will also assist me to check the impact of this intervention program on my learner performance.*

Researcher: **Which method of representation would you advice/share with other physics teachers to assist learners that might experience difficulties regarding understanding the topic of electromagnetism?**

TE3: *In this digital era, I will advise physical science educators if ever they can, to go with ICT tools like simulations and videos as the best method of representing concepts like EMI to Grade 11 learners*.

APPENDIX F4: TE4`S SEMI-STRUCTURED INTERVIEW RESPONSES.

An SSI session was conveniently carried out at TE4`s school and in her quite office, after school hours to avoid disrupting her lessons and other school programs. The SSI session was carried out three days after the video recorded EMI lesson observation. The entire SSI session lasted for approximately twenty-seven minutes. The following is a detailed narrative account of what transpired during TE4`s SSI session

Researcher: **Are you currently registered for any further studies?**

TE4: *Not yet. But I will see as time progresses.*

Researcher: **Have you previously participated in any Physical Sciences continued professional development training program/workshop before?**

TE4: *No. I have never attended content workshops at cluster and district levels. The reason is because in such workshops, the discussions tend to be centred more especially on grade 12 topics. Yet I am only teaching grade 11*

Researcher: **Could you tell me about your background in EMI and teaching of EMI?**
TE4: *My EMI background is very bad. I have never done well especially in electromagnetism. However, with time i gradually gain confidence through teaching the section. When teaching the EMI section,*
Researcher: **What are your personal views about the training your received during this period of intervention? Do you think that such a training experience added any value to your teaching profession?**

TE4: *It was quite good and worth it. The use of content representation tool followed by a video recorded lesson assisted a lot in boosting my confidence when teaching this topic. I personally appreciate the effectiveness of this intervention.*

Researcher: **Have you ever taught the section of electromagnetic induction in the past? If so, how many years of experience do you hold in teaching the grade 11 section of electromagnetic induction?**

TE4: *Honestly speaking, I have never taught this section in my entire career. In fact, this is my first year to be teaching the grade 11 learners. I have actually come to realise that there is a lot involved in the teaching of electromagnetic induction. Like just telling learners what happens without any form of demonstration will not make any sense to them.*

Researcher**: If you were to score yourself out of 10, what score would you give yourself in as far as your understanding of CAPS syllabus is concerned?**

TE4: *I wouldn't give myself 10 out 10, neither would I give myself 3 out of 10. Perhaps I would score myself with a 6 out of 10. There are a lot of bullets in the Physical Sciences CAPS document, most of which require interpretation aided with other sources like textbooks and examination guidelines. I am still in the process of trying to understand the expectations of the CAPS syllabus.*

Researcher: **What strategies and representations would you employ If you are to be given another chance to re-teach magnetic flux and Faraday`s law**

TE4: *It`s just that my school is very poorly resourced when it comes to lab equipment. I could have done some experiments with the learners. But net time I think I will have to download some pre-selected internet videos based on magnetic flux and Faraday`s law. The videos will assist me to explain the concepts easily, i think.*

Researcher: **What challenges of representation, do you think are usually encountered when treating magnetic flux and Faraday`s law?**

TE4: *It's very difficult for learners to understand the whole idea behind Faraday`s law of electromagnetic induction without the assistance of some practical representation. Just mere verbal explanations and chalkboard notes are not enough.*

Researcher: **What do you think makes the teaching and learning of EMI to be difficult for students?**

TE4: *Not only learners but even teachers like me, have some serious misconceptions in the section of EMI. Explaining the EMI phenomena without being supported by any demonstration or simulation experiment is a non-starter.*

Researcher: **What is it that you liked about the intervention? What did you learn about teaching EMI to the Grade 11 learners?**

TE4: *Having to video-record the lesson on EMI and playback the video to check my areas of strength and areas that I need to improve is what I like most about this intervention.*

Researcher: **What is it that you did not like about the intervention?**

TE4: *There is nothing I hate more than writing and completing documents. Doing my lesson preparations after which I also have to complete the content representation tool, that's a hell lot of work. Even though it's worth it but it brings extra work on my table.*

Researcher: **How would you go about teaching this topic or any other difficult topic in future?**

TE4: *I have already fallen in love with the content representation tool with its associated components. I think I will adopt it as my lesson preparation tool. I also love that in all my lessons involving concepts such as EMI, I will record and playback the lesson afterwards in order to develop my own personal professional growth. I will also further try to adopt the use of actual experiments and ICT gadgets in my representation of content*

Researcher: **Is there anything else which you wish to learn and know about EMI, teaching EMI and PCK for your continued professional growth?**

TE4: *Yes, yes. I wish if someone can explain to me the physical significance of the negative sign present in the mathematical formulations of Faraday`s law. I also require some convincing explanation about the difference between magnetic flux and magnetic field strength. If a learner were to ask whether a coil has area, how would I provide a convincing explanation?*

Researcher: **How do you usually teach EMI in your own way as an experienced teacher?**

TE4: *Fortunately, this is my first time to be teaching this section. That is why I had to explain it straight from the textbook. Afterwards I just gave my learners some classwork and homework activities all in form of worksheets.*

Researcher: **To what extend does your approach to teaching topics such as EMI impact on your self-efficacy?**

TE4: *Not to a greater extend because EMI is just a smaller section in our Physical sciences CAPS curriculum.*

Researcher: **How do you plan to assess or seek for the evidence that learners have successfully been able to address the goals of your lesson in the topic of EMI?**

TE4: *Besides the classwork and homework which I have already given them in the form of worksheets, I` m also going to assess them using your post-test based on electromagnetism and record the marks.*

Researcher: **Which method of representation would you advice/share with other physics teachers to assist learners that might experience difficulties regarding understanding the topic of electromagnetism?**

TE4: *Use of actual experiments, ICT tools in the form simulations and videos is more appropriate representation method for learners who might find it difficult to understand EMI. Some video simulations can also be of great use in our poor schools.*

APPENDIX G: SCORING RUBRIC Adapted from (Coetzee, 2018)

RUBRIC FOR SCORING TEACHER`S PERSONAL & ENACTED PCK				
Component prompts	Limited (1)	Adequate (2)	Developing (3)	Exemplary (4)
A. Knowledge of curricular saliency				
A_0: How were key ideas selected?	- Main ideas are restricted to the headings in the CAPS document. - Main ideas include pre-concepts. - There iso evidence of attention to proper sequencing	- Main ideas include the headings in the CAPS document plus one or more other ideas which are sub-ordinate ideas. - There is no indication that attention was paid to proper sequencing.	- Appropriate main idea(s) other than the headings in the CAPS document are included. - There are indications that attention was paid to sequencing of the ideas.	- Selection of main ideas reflects the conceptual logic associated with the topic, (not necessarily using the wording of headings in the CAPS document). - Proper sequencing is evident
A_1: What do you intend learners to know about each key idea?	- Main ideas are repeated/ restated without further development into subordinate ideas. - Sub-ordinate ideas were copied from the CAPS. - Identified subordinate ideas are mainly inappropriate	- Main ideas are repeated with inadequate development into sub-ordinate ideas. - Important sub-ordinate ideas are omitted; however, those identified are mainly correct. - Subordinate ideas are limited to being aware of the definitions, equations and/or terms.	- Appropriate subordinate ideas are identified and links to key ideas are shown. - The list of sub-ordinate ideas is not extensive -Subordinate ideas that account for the application of equations and definitions are identified.	- Identifies correct subordinate ideas and explain links to main ideas. - Identifies sub-ordinate ideas that focus on understanding of the concepts. - Subordinate ideas constitute an exhaustive list of concepts to be taught. - There is evidence of appropriate sequencing of ideas.
A_2: Why is it important for learners to know this key idea?	- Reasons provided are limited to the general benefit of education - Key idea is restated - Reasons provided indicate no logical link between the key/ subordinate idea(s) and its importance for	- Reasons provided exclude considerations such as scaffolding / sequential development. - Reasons include reference to the selected key and sub-ordinate ideas rather than topics that follow	- Reasons provided include evidence of understanding of conceptual scaffolding / sequential development.	- Reasons provided include conceptual scaffolding / sequential development of understanding of specified subsequent topics in the subject. - Understanding of the importance of the key idea in relation to other ideas in the

	key ideas that follow sequentially.	sequentially on the key idea.		curriculum and in the learners’ understanding of the world around them is evident.
A_3: What concepts need to be taught before teaching this key idea?	- The pre-concepts mentioned are not appropriate for the key idea. -There is inadequate evidence of knowledge about sequencing. - Identified pre-concepts are in fact sub-ordinate ideas of the selected key idea.	- Identified concepts refer to elementary concepts generally regarded as basic to the subject or topic. - Pre-concepts that are directly related to key idea were omitted	- Identified pre-concepts consist of those required to understand the current key idea.	- Identified pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the key ideas of the current topic. - Concepts from other topics having logical links with the key idea are included.
A_4: What else do you know about this idea-(that you don’t intend learners to know yet?)	- There is no evidence of knowledge about sequencing or scaffolding. - Placing of concepts is illogical.	- There is some evidence of knowledge about sequencing or scaffolding. - Ideas that are unlikely to be discussed at school level are selected -Knowledge of curriculum is not evident.	- There is evidence of knowledge about sequencing and scaffolding of concepts. - Content knowledge is evident. - Key ideas following the current key idea are included	- There is evidence of knowledge about logical scaffolding and sequencing of ideas in the topic and subject. - Selected ideas indicate strategic thinking about content. -Rich content knowledge is evident.

Component prompts	Limited (1)	Adequate (2)	Developing (3)	Exemplary (4)
B. Knowledge of learner understanding				
B_1: What do you consider difficult about teaching this idea?	- Knowledge about this component is not evident - Main ideas are rephrased or restated. - Broad topics without specifying the actual sub-concepts that	- An appropriate difficulty related to one of the main ideas is identified and clearly formulated.	- Appropriate difficulties for two of the main ideas are identified and clearly formulated.	- Appropriate difficulties for all three selected main ideas are identifies and clearly formulated. - The response mentions gate keeping concepts that when not fully understood

	are problematic are identified.			add to the difficulty of the main idea.
B$_2$. What are typical learners' misconceptions when teaching this idea?	- No misconceptions are identified. - Selection of inappropriate misconceptions not related to the topic - The response reveals own misconceptions - The response is poorly formulated	- Identifies common learner errors rather than misconceptions. (Such as lack of elementary pre-concepts or problems with mathematical concepts). - Identifies very basic alternative ideas or difficulties that are not normally documented as misconceptions related to the topic.	- Identifies at least one misconception - Identifies gaps in pre-concepts. - Important well documented misconceptions that are related to the conceptual understanding of the main idea are omitted.	- Identifies and describes a number of misconceptions or gaps in pre-concepts. - An indication of knowledge about misconceptions and their origin is evident.

Component prompts	Limited (1)	Adequate (2)	Developing (3)	Exemplary (4)
C. Conceptual Teaching Strategies				
C$_1$: What teaching strategies would you use to teach this idea?	- List of general strategies without indications of how they will be employed, is given. - The suggested strategies are not conceptually connected to the key-idea.	- The response indicates general teaching strategies with limited explanation of application. - There is no evidence of acknowledgement of student prior knowledge and misconceptions. - Insufficient conceptual development - The response lacks aspects of curriculum saliency.	- The overall strategy is workable. - At least one aspect related to curriculum saliency or sequencing is considered. - At least two different levels of representation to enforce an aspect or concept with explanatory notes are suggested. - There is evidence of encourageme	- An overall excellent and creative strategy to teach the required concept are presented. - Use of macroscopic, visual and symbolic representations to enforce aspect(s) of a concept are given with explanatory notes. - The response considers confirmation/confrontation of student prior knowledge and/ or misconceptions and aspects related to sequencing. - The suggested strategy is highly learner centred lesson. -There is evidence that strategy will support

		- Use is made of macroscopic and/or symbolic representations with no linking explanatory notes. - Limited involvement of learners is evident.	nt of learner involvement.	conceptual understanding. - There is evidence of integration and creative interaction of other components.
Component prompts	Limited (1)	Adequate (2)	Developing (3)	Exemplary (4)
C_2: What questions would you consider important to ask in your teaching strategy?	- Concepts are listed without relating them to the key idea. - There is no evidence of questions that will support conceptual understanding. - There is no evidence of sequential development of concepts.	- Questions are basic and mostly rote learning questions are posed. - Questions do not require higher order thinking skills. - Knowledge of sequencing towards conceptual development is not evident.	- Some questions require higher order thinking skills - Attention being paid to sequencing for conceptual development is not evident	- Questions require higher order thinking skills. - Questions lead to constructive development of concepts - Knowledge of sequencing is evident.
D. Representations				
D: What representations would you use in your teaching strategy?	- The representations mentioned are vague and not specific to the key idea. Representations are mentioned with no explanation of specific links to the concepts considered. - The suggested representations are not feasible.	- The selection of representations (visual and / or symbolic) is insufficient. - There is no evidence how the use of the representation will lead to increased understanding of concepts.	- An adequate selection of representations (visual and / or symbolic) sufficient to support explanation of concepts is presented. - Some evidence is given of the use of representations to support conceptual development.	- Extensive use of representations (visual and symbolic / graphical / pictorial / diagrammatic) to enforce specific aspect(s) of concepts being developed are suggested. - Explanatory notes link the different kinds of representations to aspect(s) of the concepts being explained.

APPENDIX H: GRADE 11 BASELINE-TEST MECHANICS

1.1 When a spaceship moves at constant velocity, it means that the resultant force acting on the body is zero. This phenomenon is best explained by

A Newton’s First Law.

B Newton’s Second Law.

C Newton’s Third Law.

D Newton’s Universal Gravitational Law. (2)

1.2 A rocket of mass M, experiences a gravitational force F on the surface of the Earth, which has a radius R. The rocket blasts off to a distance R, vertically above the surface of the Earth, where its mass is now ¾ M. The gravitational force it experiences at this height is . . .

A F

B 3 F

C ¾ F

D 3/16 F (2)

1.3 Acceleration due to gravity (g), at a particular point, on earth is 9,8 m.s–2. If the radius of the earth were to be halved and its mass were to remain the same, then the acceleration due to gravity will be:

A 4,9 m.s–2

B 9,8 m.s–2

C 19,6 m.s–2

D 39,2 m.s–2 (2)

1.4 An astronaut has a weight of W on earth. He lands on a planet with mass three times greater than the earth and a radius twice that of the earth. What is the weight of the astronaut on this planet? Take the radius of the earth as R.

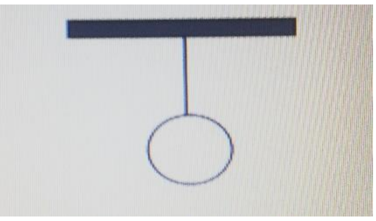
A 3/16W

B 3/4W

C 3/2W

D 3W (2)

1.5 A sphere is attached to a string, which is suspended from a fixed horizontal bar as shown in the sketch.



The reaction force to the gravitational force exerted by the earth on the sphere is …

A the force of the bar on the sphere.

B the force of the string on the sphere.

C the force of the sphere on the earth.

D the force of the bar on the string (2)

1.6 The frictional force acting on a sliding object is …

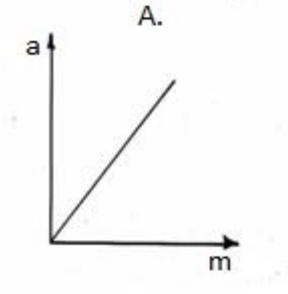
A dependent of the apparent area of contact.

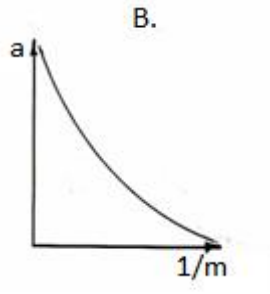
B proportional to the normal force.

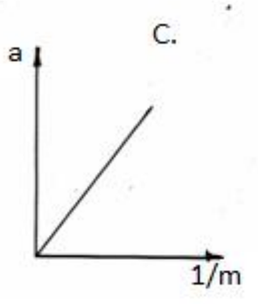
C dependent of the velocity of motion.

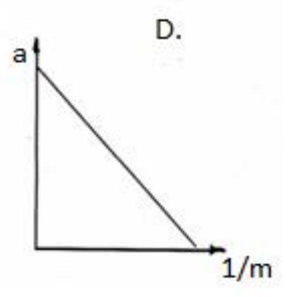
D independent of the type of surface. (2)

1.7 Which one of the graphs below best represents the relationship between acceleration and mass of an object



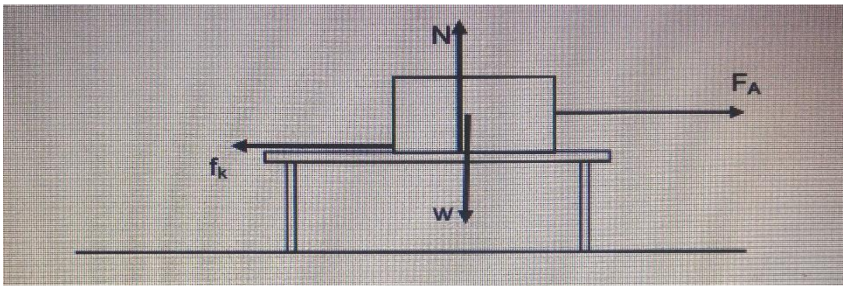






(2)

1.8 The force diagram below shows the forces acting on a box.



Which ONE of the following statements about forces acting on the box is CORRECT?

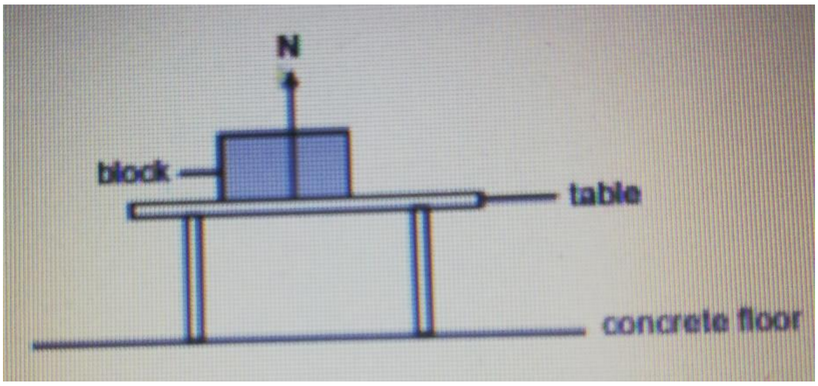
A N is greater than w

B w is greater than N

C F_A is greater than f_k

D F_A is equal to f_k (2)

1.9 A block rests on a table. The table stands on a concrete floor. The normal force is represented by N, as shown in the diagram below.



Which ONE of the following forces will form an action-reaction pair with the normal force (N)?

A Force of the block on the Earth

B Force of the table surface on the block

C Force of the block on the table

D Weight of the block on the concrete floor (2)

1.10 A physical quantity that describes the rate of change in velocity of a body is called …

A inertia.

B force.

C acceleration.

D weight. (2)

1.11 Inertia is the tendency of an object to …

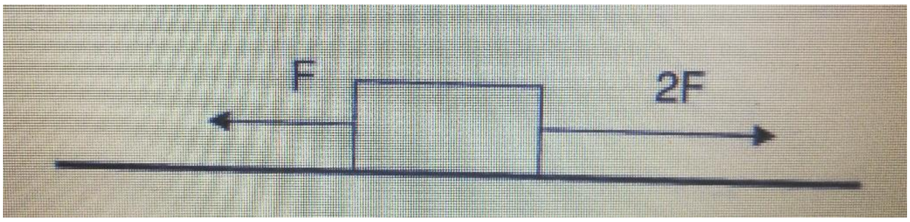
A maintain its mass.

B continue in a state of non-uniform motion.

C remain at rest or in the state of uniform motion.

D maintain its velocity when a non-zero net force is acting on it. (2)

1.12 A block is placed on a horizontal surface with negligible friction. Forces F and 2F are simultaneously applied on the block as shown in the diagram below.

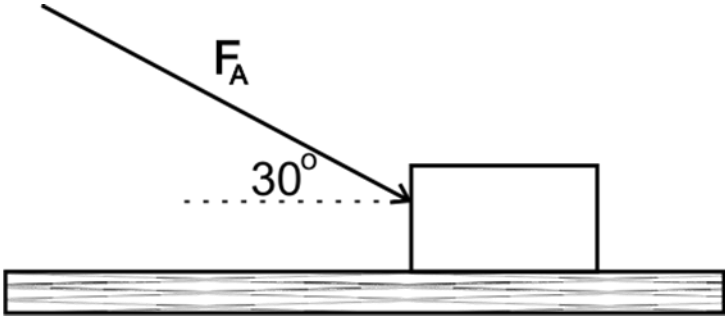


Which ONE of the following statements correctly describes the motion of the block?

- **A.** The block at constant velocity to the right
- **B.** The block moves with increasing acceleration to the right.
- **C.** The block moves with constant acceleration to the left
- **D.** The block moves with constant acceleration to the right. (2)

1.13 A learner pushes a block of mass M at a constant velocity with a stick over a rough horizontal surface with a force F at 30º to the horizontal.

The free-body diagram below shows all forces acting on the block.



Which ONE of the following indicates the CORRECT relationship between the magnitude of the forces in the free-body diagram?

A $F_f = F_A$

B $F_f = F_A \sin30^o$

C $F_f = F_A \cos30^o$

D $F_f = F_A \cos60^o$. (2)

1.14 The net force acting on a moving object is **zero**. The object will continue its motion with …

A. constant acceleration

B. constant velocity

C. increasing velocity

D. Decreasing acceleration. (2)

1.15 A satellite experiences a gravitational force of magnitude F on the surface of the earth. The radius of the earth is R. The satellite now circles the earth at an unknown height above the surface of the earth and experiences a gravitational force of magnitude ¼ F. This unknown height above the surface of the earth is ….

A R

B 2R

C 3R

D 4R (2)

1.16 A net force F which acts on a body of mass m causes an acceleration a. If the same net force F is applied to a body of mass 2m, the acceleration of the body will be …

A 1/4a

B 1/2a

C 2a

D 4a (2)

1.17 Two forces, of 3 N and 5 N respectively, act simultaneously at the same point. The magnitude of their resultant force is 2 N if the angle between them is:

A 0°

B 90°

C 180°

D 360° (2)

1.18 A car moves, under the influence of its engine, at a constant velocity along a straight horizontal road. Which ONE of the following statements regarding this motion is TRUE?

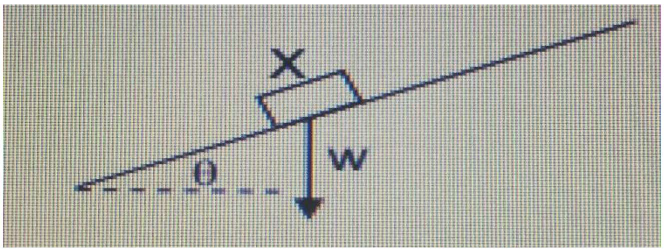
A A non-zero resultant force acts on the car.

B No forces act on the car.

C The resultant force on the car is zero.

D The car experiences no frictional force. (2)

1.19 Object X of weight w is at rest on a plane inclined at an angle θ with respect to the horizontal as shown below.



Which ONE of the following gives the magnitude of the frictional force on the object?

A wsinθ

B wcosθ

C w/sinθ

D w/cosθ (2)

1.20 When a bus suddenly accelerates from rest, standing passengers tend to fall backwards. This observation is best explained using ...

A Newton’s first law of motion.

B Newton’s second law of motion.

C Newton’s third law of motion.

D Newton’s law of universal gravitation. (2)

TOTAL MARKS [40]

APPENDIX I: Grade 11: Post-test: Electromagnetism

1.1 A coil is placed inside a magnetic field and rotated clockwise to induce an electromotive force (emf).

Which ONE of the following changes will increase the induced emf?

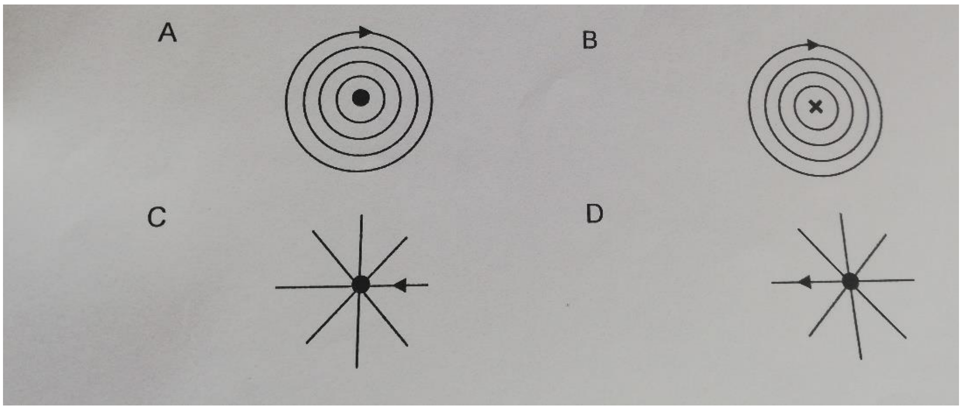
A Rotating the coil slower

B Increasing the speed of coil rotation

C Changing the polarity of the magnets

D Decreasing the number of coil windings/turns (2)

1.2 which ONE of the following sketches below represents the CORRECT magnetic field pattern around a straight current-carrying conductor?



(2)

1.3 Which ONE of the following does not influence the induced emf around a loop of a conductor?

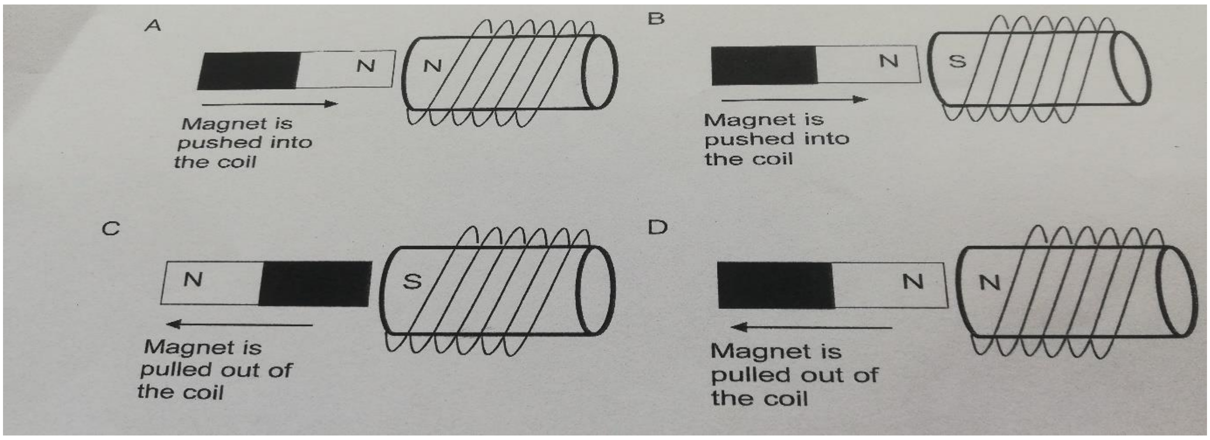
A Time

B Change in magnetic flux

C Number of turns

D speed of rotation of the loop (2)

1.4 In which ONE of the sketches below is the induced polarity of the coil CORRECTLY indicated?



1.5 Magnetic flux through a wire loop depends on:

A. thickness of the wire

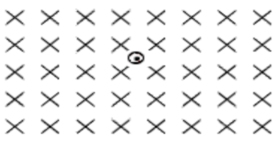
B. resistivity of the wire loop

C. geometry of the wire loop

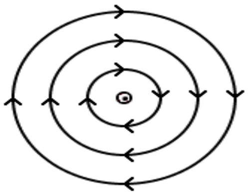
D. material that the wire is made of (2)

1.6: Which of the following diagrams accurately portrays the magnetic field resulting from a wire carrying current directed out of the page?

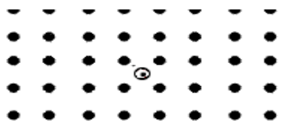
A.



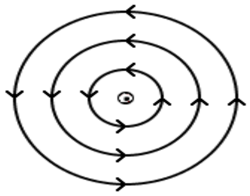
C.



B.

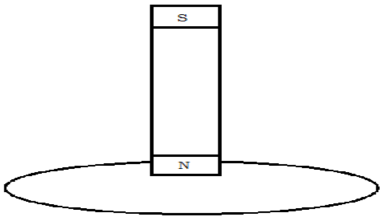


D.



(2)

1.7: A magnet is slowly descending into a loop of wire.



In which direction is the induced current in?

A. Clockwise viewed from above

B. Anticlockwise viewed from below

C. No current is induced

D. Not enough information (2)

1.8: A square loop of wire with 10 turns and a side length of 1**m** is placed in a changing magnetic field. If the magnetic field changes from 2**T** to 4**T** within 8**s**, what is the average induced EMF?

A. 1.25 V

B. 2.5 V

C. 0 V

D. 5 V (2)

1.9: A square coil of wire with a side length of 10**cm** is looped around 10 times. A magnetic field through the loop coil parallel to the axis of the coil increases linearly from 1**T** to 2**T** within 5**s**. If this loop of wire has a resistance of 2**Ω**, what is the induced current in the loop?

A. 100 A

B. 10 A

C. 1 A

D. 0.01 A (2)

1.10: When a current run through a wire, a magnetic field is created. However, computer cables create little to no magnetic field external to their insulation. How is this possible? (Hint: computer cables contain multiple wires inside)

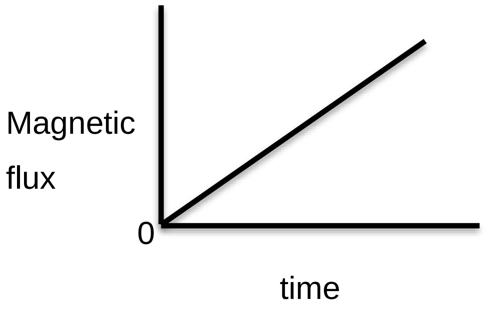
A. The wires and cables are insulated with plastic.

B. The supply and return wires carry current in opposite directions and their magnetic fields essentially cancel out.

C. The supply and return wires carry current in the same direction and their magnetic fields essentially cancel out.

D. The currents are too small to create a significant magnetic field. (2)

1.11 The graph shows how the magnetic flux passing through a loop of wire changes with time.



What feature of the graph represents the magnitude of the emf induced in the loop?

A. the area enclosed between the graph line and the time axis

B. the area enclosed between the graph line and the magnetic flux axis

C. the inverse of the gradient of the graph

D. the gradient of the graph (2)

1.12: To increase the magnetic flux through a coil of wire.

i) Increase the magnitude of the magnetic field that passes outside the loop

ii) Increase the magnitude of the magnetic field that passes through the loop.

iii) Increase the cross-sectional area of the loop.

iv) Orient the loop so its normal vector is perpendicular to the external magnetic field direction.

Which ONE of the above statements are correct?

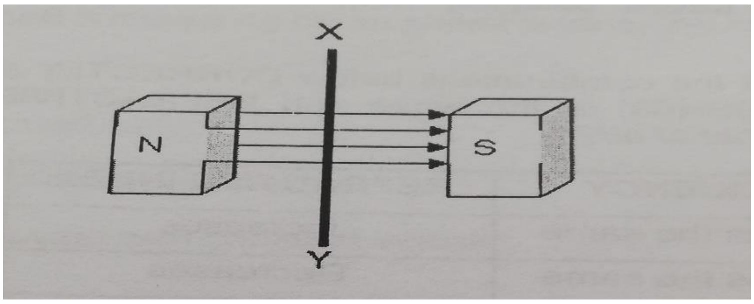
A ii, iii and iv

B i, ii and iii

C ii and iii

D i, ii, iii and iv (2)

1.13 A conducting wire XY moves between two magnets as shown below.



Which ONE of the following actions can lead to an increased induced current in the wire XY? Move the wire….

A Slowly and perpendicular to the magnetic field.

B Quickly and parallel to the magnetic field.

C Quickly and perpendicular to the magnetic field

D Slowly and parallel to the magnetic field. (2)

1.14 A uniform 4.5**T** magnetic field passes perpendicularly through the plane of a wire loop 0.10m^2 in area. What flux passes through the loop?

A. 5.0 webers

B. 0.135 webers

C. 0.45 webers

D. 0.25 webers (2)

1.15 A coil is placed in a changing magnetic field and an emf is induced.

What happens to the induced emf if the rate of change of magnetic field quadruples?

A. The emf increases by a factor of 16.
B. The emf doubles.
C. The emf halves.
D. The emf quadruples. (2)

1.16 Electricity may be generated by rotating a loop of wire between the poles of a magnet.

The induced current is greatest when:

A. the plane of the loop is parallel to the magnetic field.
B. the plane of the loop is perpendicular to the magnetic field.
C. the magnetic flux through the loop is a maximum.
D. the plane of the loop makes an angle of 45° with the magnetic field. (2)

1.17 If the induced current in a wire loop were such that the flux it produces reinforces the change in external flux causing the current, which of the following conservation laws would end up being violated?

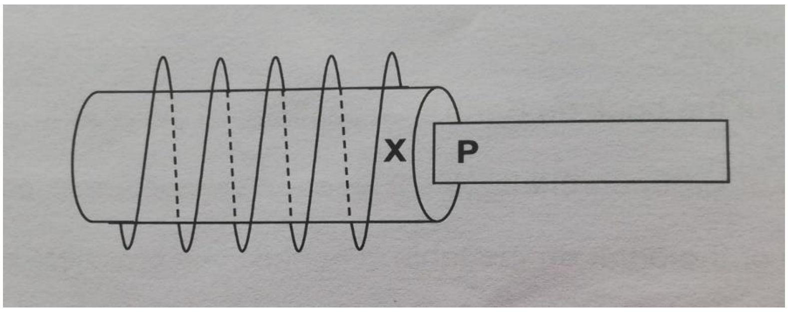
A. momentum
B. charge
C. mass
D. energy (2)

1.18 A current in a solenoid coil creates a magnetic field inside that coil.

Which one of the following is NOT CORRECT about the magnetic field strength around the coil? is directly proportional to:

A. it is directly proportional to the solenoid area.
B. it is directly proportional to the current.
C. it is directly proportional to the solenoid diameter.
D. it is directly proportional to the resistance of the coil. (2)

1.19 The diagram below shows a coil and a magnet with a pole **P**. A magnetic field is induced in the coil due to the motion of the magnet.



Which ONE of the following combinations will result in an induced magnetic field with a NORTH pole at point **X**?

	Direction of motion of magnet	Polarity of P
A	Into the coil	North
B	Up and down inside the coil	South
C	Up and down inside the coil	North
D	Into the coil	South

(2)

1.20 Consider the statements given below.

i) the SI unit of magnetic flux is the tesla (T).

ii) Magnetic flux density is a measure of the strength and direction of the magnetic field.

iii) the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux linkage.

iv) magnetic flux is a product of the parallel component of the magnetic field and cross-sectional area of the loop.

Which ONE of the following statements is/are CORRECT?

A i) and iv)

B ii) and iii)

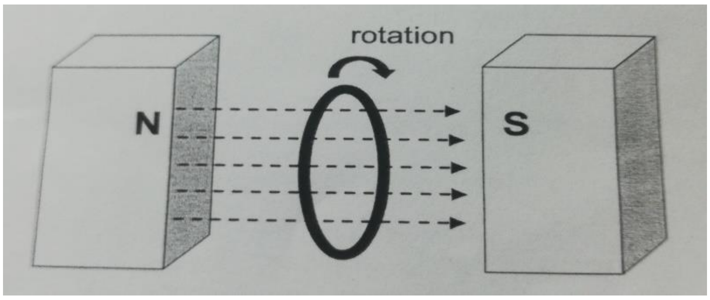
C i), ii) and iv)

D ii), iii) and iv) (2)

[40]

Section B

A circular coil with 250 windings and a radius of 0.04m is rotated clockwise inside a magnetic field with a field strength of 3.2T



2.1 Define the term magnetic flux in words

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………[2]

2.2 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the magnetic field.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………[3]

2.3 If the coil rates clockwise through an angle of 25^0, and the induced emf is 2.8V. Calculate the time in which this rotation took place.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………[3]

2.4 Name and state the law which can be used to explain the phenomenon described in QUESTION 2.3.

…………………………………………………………………………………………………

…………………………………………………………………………………………………[2]

[10]

Grand total **[50]**

APENDIX J1: PERMISSION LETTER TO MDE

HEAD OF DEPARTMENT
MPUMALANGA PROVINCIAL EDUCATION DEPARTMENT
PRIVATE BAG X11341
NELSPRUIT 1200

Dear Sir/Madam

Re: Request for permission to conduct research in Gert Sibande District secondary schools.

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your permission to allow me to conduct the above titled (in bold) physics education-based research in Gert Sibande District (more specifically in Badplaas & Mashishila circuits`) secondary schools. The target population is all grade 11 physical sciences learners and their teachers. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers’ pedagogical content knowledge (PCK) and its influence on learners’ performance in electromagnetism. Data collection is projected to ensue during the third quoter of the 2021 school calendar, a period where the grade 11 topic of electromagnetism will be treated in accordance with the revised ATP.

The CAPS curriculum was developed using a spiral approach in which students learn best by building on their current knowledge in order to promote higher order critical and creative scientific skills (CAPS, 2011). Hence the concept of electromagnetism is broadened, reinforced, and solidified each time the learners revisit it in the next grade. The challenges associated with electromagnetism such as how electricity is induced in accordance with Faraday`s law become more evident when learners in the 12th grade must be re-taught 11th grade electromagnetism before being introduced to electrodynamics. As such grade 11 concepts based on electromagnetism act as pre-requisite to grade 12 concepts of electrodynamics. Hence a strong and clear grade 11 foundation is needed.

During this study, the teacher at each of the selected schools shall be requested to complete a pre-intervention content representation instrument. The researcher shall then explain to him/her all the details of the research during intervention period. Afterwards, he/she will be requested to complete a post-intervention content representation instrument which shall be used in conjunction with his/her lesson preparation based on electromagnetic induction. The teacher shall then be accorded the chance to enact their PCK by teaching electromagnetic induction to his/her usual learners at your school. The lesson shall be video recorded. Only one of his/her lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson will be video recorded from the back of the class to ensure that learners' identities are hidden. After the lesson, the teacher shall be accorded the chance to view the video recorded lesson for him/her to reflect on his/her teaching methods. Their PCK shall then be investigated, captured, and evaluated using a content representation (CoRe) tool, video recorded classroom observations and video stimulated recall (VSR) interview sessions. Furthermore, the teacher shall be requested to complete a post questionnaire and invited to attend a mini-interview session with the researcher in which he/she shall present his/her personal views about the impact of PCK intervention on learner performance in electromagnetism. The interview shall be held at school and is expected to last for about 30minutes. The researcher's visits to schools will not interfere with the existing academic program of your school. As part of the normal formative and/or summative assessment, the grade 11 learners shall also write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism. The findings of this study shall be made available to the Mpumalanga department of education as and when needed.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcome of data analysis shall not allow for the re-identification of the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and the identities of the participants and their affiliated institutions will be kept confidential and will be used solely for the purpose of this research. The school name, educator names, and learner names shall be strictly confidential in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, the willingness of educators and learners to participate in the research study shall be strictly on voluntary basis. Both educator and learner participants have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to. I have also attached my full research proposal for further details.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I would greatly appreciate it if you can grant me the permission and opportunity to proceed with my study as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely …………………………………………………

Mr LM DZIKITI (Physics Education)
Cell: 0787510784 / 0712670033
Email: munodadz@gmail.com
listerdz@yahoo.com

APENDIX J2: PERMISSION LETTER TO THE CIRCUIT MANAGER

The Circuit Manager
ACB Circuit
Elukwatini 1192
Mpumalanga

Dear Sir/Madam

Re: Request for your consent and permission to conduct research at schools in your circuit

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your consent and permission to allow me to conduct the above titled (in bold) physics education-based research at the school under your governance. The target population shall be all grade 11 physical sciences learners and their teachers. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers’ method of teaching and its influence on learner performance. Data collection is projected to start during the third term of the 2021 school calendar, a period where the grade 11 topic of electromagnetism will be treated in accordance with the revised ATP.

During this study, the teacher shall be requested to complete a pre-intervention instrument. The researcher shall then explain to him/her all the details of the research during intervention period. Afterwards, he/she will be requested to complete a post-intervention instrument which can also be used in conjunction with his/her lesson preparation based on electromagnetic induction. The teacher shall then be accorded the chance to teach electromagnetic induction to his/her usual learners at your school. The lesson shall be video recorded. Only one of his/her lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson shall be video recorded from the back of the class to ensure that learners’ identities are hidden. After the lesson, the teacher shall be accorded the chance to view the video recorded lesson for him/her to reflect on his/her teaching methods. Furthermore, the teacher shall be requested to complete a post questionnaire and also invited to attend a mini-interview session with the researcher. During the interview, he/she shall present his/her personal views about the influence of his/her teaching strategies and, impact of intervention on learner performance in electromagnetism. The interview shall be held at his/her school and shall be scheduled for at about 30 minutes. The researcher's visits to the school shall not interfere with the existing academic program of your school. As part of the normal formative and/or summative assessment, the grade 11 learners shall also write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcome of data analysis shall not allow for the re-identification of the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and the identities of the participants and their affiliated institutions will be kept confidential and will be used solely for the purpose of this research. The school's name, educator names, and learner names shall be strictly confidential in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, the willingness of educators and learners to participate in the research study shall be strictly on voluntary basis. Both educator and learner participants have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I would greatly appreciate it if you can give your consent and the permission to proceed with my studies as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely ………………………………………………

If you ACCEPT/DECLINE the request for schools in your circuit to participate in the research study as outlined above, please show by completing the form below.

I ……………………………………………….. (your names and surname), the Circuit manager of

…………………………………………………………circuit **ACCEPT/DECLINE** (underline the applicable) to give my consent for schools in my circuit to participate in the research outlined above.

Circuit Manager signature: ………………………………… Date: ……………………..

Researcher signature: ……………………………………. Date: ……………………..

Supervisor Signature: ……………………………………… Date: …………………….

APENDIX J3: PERMISSION LETTER TO THE SCHOOL PRI\NCIPAL

The principal

Dear Sir/Madam

Re: Request for consent and permission to conduct research at your school

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your consent and permission to allow me to conduct the above titled (in bold) physics education-based research at your school. The target population shall be all grade 11 physical sciences learners and their teachers. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers' method of teaching and its influence on learner performance. Data collection is projected to start during the third term of the 2021 school calendar, a period where the grade 11 topic of electromagnetism will be treated in accordance with the revised ATP.

During this study, the teacher shall be requested to complete a pre-intervention instrument. The researcher shall then explain to him/her all the details of the research during intervention period. Afterwards, he/she shall be requested to complete a post-intervention instrument which can also be used in conjunction with his/her lesson preparation based on electromagnetic induction. The teacher shall then be accorded the chance to teach electromagnetic induction to his/her usual learners at your school. The lesson shall be video recorded. Only one of his/her lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson will be video recorded from the back of the class to ensure that learners' identities are hidden. After the lesson, the teacher shall be accorded the chance to view the video recorded lesson for him/her to reflect on his/her teaching methods. Furthermore, the teacher shall be requested to complete a post questionnaire and invited to attend a mini-interview session with the researcher. The interview shall be held at the school and is expected to last for about 30 minutes. The researcher's visits shall not interfere with the existing academic program of your school. As part of the normal formative and/or summative assessment, the grade 11 learners shall also write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcome of data analysis shall not allow for the re-identification of the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and the identities of the participants and their affiliated institutions will be kept confidential and will be used solely for the purpose of this research. The school name, educator names, and learner names shall be strictly confidential in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, the willingness of educators and learners to participate in the research study shall be strictly on voluntary basis. Both educator and learner participants have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I would greatly appreciate it if you can grant me your consent and the permission to proceed with my studies as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely ………………………………………………

LM DZIKITI (Physics Education)

Cell: 0787510784 / 0712670033

Email: munodadz@gmail.com

listerdz@yahoo.com

If you ACCEPT/DECLINE the request for your school to participate in the research study as outlined above, please show by completing the form below.

I ………………………………………………….. (your names and surname), the principal of

………………………………………………………secondary school **ACCEPT/DECLINE** (underline the applicable) to give consent for my school to participate in the research outlined above

Principal signature: ……………………………………….. Date: ……………………..

Researcher signature: …………………………………… Date: ……………………..

Supervisor Signature: ……………………………………… Date: …………………….

APENDIX J4: PERMISSION LETTER THE GRADE 11 PHYSICAL SCIENCES EDUCATOR

Dear Physical Sciences Educator

Re: Request for permission to conduct research at your school & consent to video record your lesson based on grade 11 topic of electromagnetism

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your permission to allow me to conduct the above titled (in bold) physics education-based research at your school. The target population will be all your grade 11 physical sciences learners and (you) their teacher. I am also requesting for your consent to video-record only one of your lessons based on electromagnetic induction and Faraday`s law while it is in progress from the beginning till the end. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers' method of teaching and its influence on learner`s performance. The lesson on grade11 electromagnetic induction & Faraday`s law which needs video-recording, is also projected to be treated during the third term of the 2021 school calendar in accordance with the revised ATP. The lesson will be video captured by any one of your learners from whom I shall also seek for consent.

During this study, you shall be requested to complete a pre-intervention content representation instrument. The researcher will then explain to you all the details of the research during intervention period. Afterwards, you will be requested to complete a post-intervention content representation instrument which should be used in conjunction with your lesson preparation based on electromagnetic induction. As an in-service teacher, you will then be accorded the chance to teach electromagnetic induction to your usual learners at your school. Your lesson will be video recorded. Only one of your lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson will be video recorded from the back of the class to ensure that learners' identities are hidden. The video recorded lesson shall be expected to last for an hour. After the lesson, you shall be accorded the chance to view your video recorded lesson for you to reflect on your teaching methods. This might take at most 25 minutes in which case you shall also be expected to respond to some few questions from the researcher based on the recorded lesson. Furthermore, you shall be requested to complete a post questionnaire and invited to attend an interview session with the researcher in which you present your personal views about the influence of your teaching strategies and, impact of intervention on learner performance in electromagnetism. The interview session shall be held at your school and is expected to last for at most 30 minutes. The researcher’s visits to the schools will not interfere with the existing academic program of each school. As part of the normal formative and/or summative assessment, your grade 11 learners will also write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcomes of data analysis shall not allow for the re-identification of all the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and your identity as a participant will be kept confidential and will be used solely for the purpose of this research. Your name shall be strictly confidential and will not be divulged in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, your willingness to participate in the research study shall be strictly on voluntary basis. As a participant, you have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I would greatly appreciate it if you can grant me your permission to participate in the research study and give your consent to video record your lesson as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely ………………………………………………

LM DZIKITI (Physics Education)

Cell: 0787510784 / 0712670033

Email: munodadz@gmail.com

If you ACCEPT/DECLINE to participate in the study and to also give your consent to video-record your electromagnetic induction lesson from the beginning till its concluded, as outlined above, please show by completing the form below.

I ……………………………………………….. (your names and surname), an educator at ………………………………secondary school **ACCEPT/ DECLINE** (underline the applicable) to participate in this study and i **DO/DO NOT** give my consent to video-record one of my lessons based on electromagnetic induction/Faraday`s law from the start until its concluded.

Educator signature: ……………………………………….. Date: ……………………..

Researcher signature: ……………………………………. Date: ……………………..

Supervisor Signature: ……………………………………… Date: …………………….

APENDIX J5: PERMISSION LETTER TO THE SCHOOL GOVERNING BODY

The SGB

Dear Sir/Madam

Re: Request for consent and permission to conduct research at your school

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your consent and permission to allow me to conduct the above titled (in bold) physics education-based research at the school under your governance. The target population shall be all grade 11 physical sciences learners and their teachers. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers' method of teaching and its influence on learner performance. Data collection is projected to start during the third term of the 2021 school calendar, a period where the grade 11 topic of electromagnetism will be treated in accordance with the revised ATP.

During this study, the teacher shall be requested to complete a pre-intervention instrument. The researcher shall then explain to him/her all the details of the research during intervention period. Afterwards, he/she will be requested to complete a post-intervention instrument which can also be used in conjunction with his/her lesson preparation based on electromagnetic induction. The teacher shall then be accorded the chance to teach electromagnetic induction to his/her usual learners at your school. The lesson shall be video recorded. Only one of his/her lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson shall be video recorded from the back of the class to ensure that learners' identities are hidden. After the lesson, the teacher shall be accorded the chance to view the video recorded lesson for him/her to reflect on his/her teaching methods. Furthermore, the teacher shall be requested to complete a post questionnaire and also invited to attend a mini-interview session with the researcher. The interview session will last for at most 30 minutes. The researcher's visits to the school shall not interfere with the existing academic program of your school. As part of the normal formative and/or summative assessment, the grade 11 learners shall also write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcome of data analysis shall not allow for the re-identification of the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and the identities of the participants and their affiliated institutions will be kept confidential and will be used solely for the purpose of this research. The school name, educator names, and learner names shall be strictly confidential in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, the willingness of educators and learners to participate in the research study shall be strictly on voluntary basis. Both educator and learner participants have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies

I would greatly appreciate it if you can give your consent and the permission and opportunity to proceed with my studies as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely ………………………………………………

LM DZIKITI (Physics Education)

Cell: 0787510784 / 0712670033

Email: munodadz@gmail.com

listerdz@yahoo.com

If you ACCEPT/DECLINE to give your consent for the school to participate in the research study as outlined above, please show by completing the form below.

I ………………………………………………….. (your names and surname), the member of the SGB at……………………………………………………secondary school

ACCEPT/DECLINE (underline the applicable) to give my consent for our school to participate in the research outlined above

SGB signature: ………………… Designation: ………………………….. Date: ……………

Researcher signature: …………………………………… Date: ……………………..

Supervisor Signature: ……………………………………… Date: …………………….

APENDIX J6: PERMISSION LETTER TO THE PARENT/GUARDIAN

Dear Parent/Guardian

Re: Request for your consent for minors to participate in a physics education research study

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am humbly requesting for your consent to allow your child to participate in the above titled (in bold) physics education-based research at his/her school. The target population will be all grade 11 physical sciences learners and their teachers. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers' methods of teaching and its influence on your child`s performance. Data collection is projected to start during the third term of the 2021 school calendar, a period when the grade 11 topic of electromagnetism will be treated in accordance with the revised ATP.

During this study, the teacher shall be requested to complete a pre-intervention instrument. The researcher will then explain to him/her all the details of the research during intervention period. Afterwards, he/she will be requested to complete a post-intervention instrument which can also be used in conjunction with his/her lesson preparation based on electromagnetic induction. The teacher will then be accorded the chance to teach electromagnetic induction to his/her usual learners at your school. The lesson will be video recorded. Only one of his/her lessons based on electromagnetic induction shall be video recorded during lesson observations schedule. The lesson will be video recorded from the back of the class to ensure that learners' identities are hidden. After the lesson, the teacher shall be accorded the chance to view the video recorded lesson for him/her to reflect on his/her teaching methods. Furthermore, the teacher shall be requested to complete a post questionnaire and invited to attend a mini-interview session with the researcher. The interview shall be held at the school and is expected to last for about 30 minutes. The researcher's visits will not interfere with the existing academic program of your school. As part of the normal formative and/or summative assessment, your child will be invited to write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcome of data analysis shall not allow for the re-identification of the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and the identities of the participants and their affiliated institutions will be kept confidential and will be used solely for the purpose of this research. The school name, educator names, and learner names shall be strictly confidential in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, the willingness of educators and learners to participate in the research study shall be strictly on voluntary basis. Both educator and learner participants have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I would greatly appreciate it if you can grant your consent to allow your child to participate in this study as outlined above. Please do not hesitate to contact me should there be need for any further clarifications.

Yours sincerely ………………………………………………

LM DZIKITI (Physics Education)

Cell: 0787510784 / 0712670033

Email: munodadz@gmail.com

listerdz@yahoo.com

If you ACCEPT/DECLINE to give your consent for your child to participate in the research study as outlined above, please show by completing the form below.

I ………………………………………………….. (your names and surname), the parent/guardian of……………………………………………(name and surname of child) doing grade 11 at ………………………………secondary school **ACCEPT/ DECLINE** (underline the applicable) to give my consent for him/her to participate in the research study outlined above

Parent/Guardian signature: ……………………………………….. Date: ……………………..

Researcher signature: …………………………………… Date: ……………………..

Supervisor Signature: ……………………………………… Date: …………………….

APENDIX J7: PERMISSION LETTER TO THE GRADE 11 LEARNER

Dear Learner

Re: Invitation to participate in a physics education research study AND request for your consent to video record the lesson based on electromagnetic induction.

I am LISTER MUNODAWAFA DZIKITI, currently enrolled with University of Pretoria (UP) for a PhD program in Physics Education. As a requirement for the award of a Doctor of Philosophy degree in Physics, Mathematics and Technology Education, I would like to understand the **EFFECT OF A PCK INTERVENTION ON TEACHERS` PCK AND LEARNERS` PERFORMANCE IN ELECTROMAGNETISM.**

I am inviting you and requesting for your consent to be part of the above titled (in bold) physics education-based research at your school. The target population is all grade 11 physical sciences learners and their teachers. The researcher's visits will not interfere with the existing academic program of your school. Furthermore, I am also humbly requesting for your consent to assist me in video recording only one lesson based on electromagnetic induction while it is in progress from the beginning till the end. The lesson on grade11 electromagnetic induction which needs video recording, is projected to be treated during the third term of the 2021 school calendar in accordance with the revised ATP. It is imperative that I collect, analyse, and interpret data that reflects in-service teachers' method of teaching and its influence on learner`s performance in electromagnetism.

The lesson based on electromagnetic induction will be video recorded from the back of the class to ensure that learners' identities are hidden. Furthermore, if any learner`s face appears during video recording, the image will be censored during data analysis by the researcher. The video recorded lesson shall be expected to last for an hour. The video-recorded information captured during the lesson will later be transcribed during data analysis. The video recordings will be treated with strict confidentiality in accordance with research ethics protocols. As part of your normal formative and/or summative assessment, you shall also be invited to write two performance tests, a baseline (pre-test) before and the post-test after learning electromagnetism.

All ethical protocols shall be observed with strictness and the use of data collected in this study shall meet all the key ethical conditions. Data shall be de-identified before analysis and the outcomes of data analysis shall not allow for the re-identification of all the participants. This also means that data collected in this study shall remain strictly confidential and, shall only be used for academic purposes. The data collected in this study and your identity as a participant will be kept confidential and will be used solely for the purpose of this research. Your name shall be strictly confidential and will not be divulged in accordance with the university`s research ethics. However, the researcher will use pseudonyms in the dissemination phase of the research findings. Furthermore, your willingness to participate in the research study shall be strictly on voluntary basis. As a participant, you have the right to withdraw at any stage of the study. The health & safety measures as well as the standard operating procedures in line with covid-19 pandemic shall strictly be adhered to.

We would also like to request your permission to use your data confidentially and anonymously for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

Yours sincerely ………………………………………………….

LM DZIKITI (Physics Education)

Cell: 0787510784 / 0712670033

Email: munodadz@gmail.com

listerdz@yahoo.com

If you **ACCEPT/DECLINE** the invitation to participate in the study and to also give your consent to video-record the lesson from the beginning till its concluded, as outlined above, please show by completing the form below.

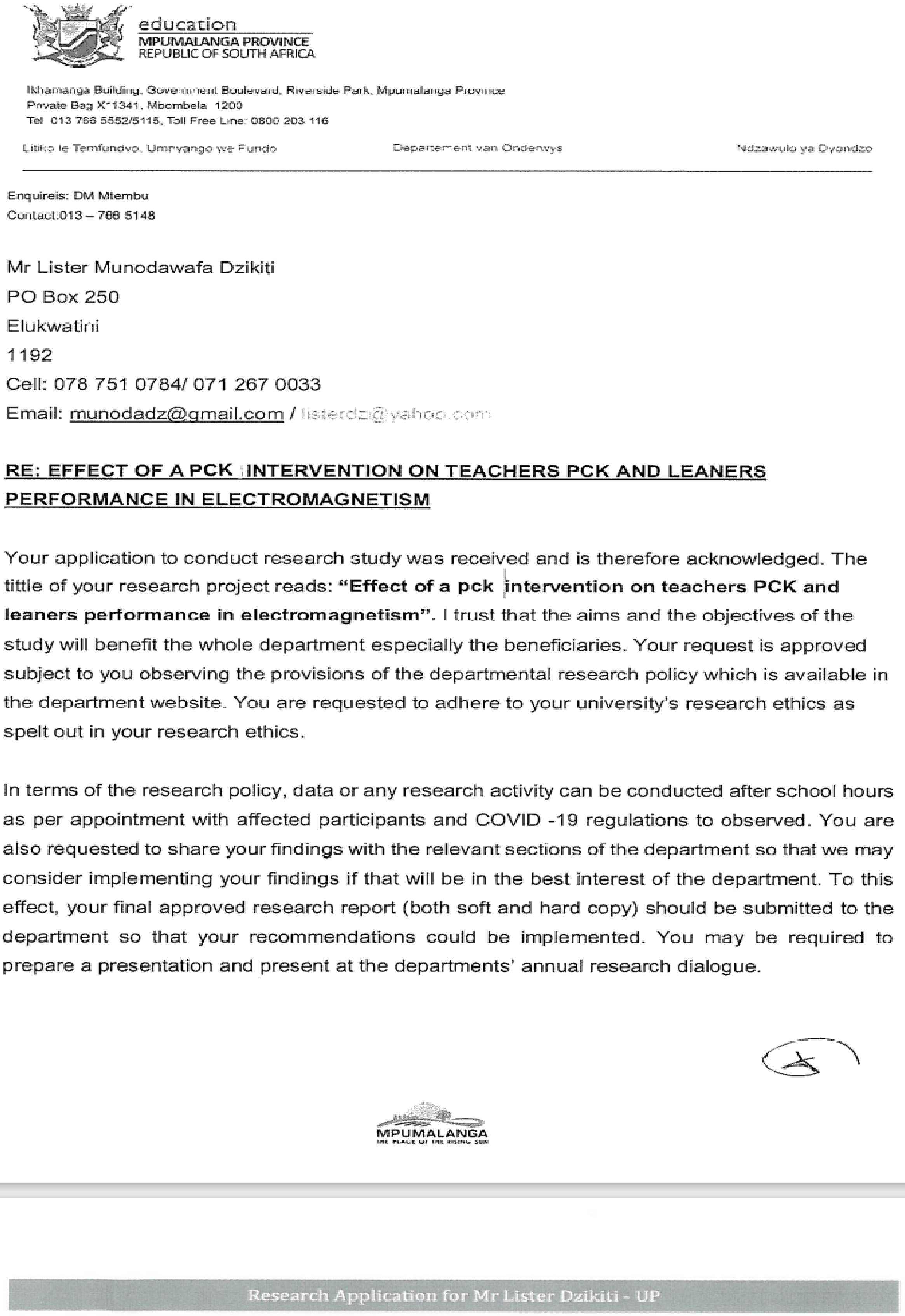
I ………………………………………………….. (your names and surname), a grade 11 learner at ………………………………………………………secondary school **ACCEPT/DECLINE** (underline the applicable) to be one of the participants of the research study outlined above and therefore **DO/DO NOT** give my consent to video record the lesson.

G11 learner signature: ……………………………………….. Date: ……………………..

Researcher signature: …………………………………… Date: …………………………

Supervisor Signature: …………………………………… Date: ………………………

APPENDIX J8: MPUMALANGA DEPARTMENT OF EDUCATION APPROVAL LETTER



education
MPUMALANGA PROVINCE
REPUBLIC OF SOUTH AFRICA

Ikhamanga Building, Government Boulevard, Riverside Park, Mpumalanga Province
Private Bag X11341, Mbombela 1200
Tel 013 766 5552/5115, Toll Free Line: 0800 203 116

Litiko le Temfundvo, Umnyango we Fundo Departement van Onderwys Ndzawulo ya Dyondzo

Enquireis: DM Mtembu
Contact:013 – 766 5148

Mr Lister Munodawafa Dzikiti
PO Box 250
Elukwatini
1192
Cell: 078 751 0784/ 071 267 0033
Email: munodadz@gmail.com / listerdz@yahoo.com

RE: EFFECT OF A PCK INTERVENTION ON TEACHERS PCK AND LEANERS PERFORMANCE IN ELECTROMAGNETISM

Your application to conduct research study was received and is therefore acknowledged. The tittle of your research project reads: **"Effect of a pck intervention on teachers PCK and leaners performance in electromagnetism".** I trust that the aims and the objectives of the study will benefit the whole department especially the beneficiaries. Your request is approved subject to you observing the provisions of the departmental research policy which is available in the department website. You are requested to adhere to your university's research ethics as spelt out in your research ethics.

In terms of the research policy, data or any research activity can be conducted after school hours as per appointment with affected participants and COVID -19 regulations to observed. You are also requested to share your findings with the relevant sections of the department so that we may consider implementing your findings if that will be in the best interest of the department. To this effect, your final approved research report (both soft and hard copy) should be submitted to the department so that your recommendations could be implemented. You may be required to prepare a presentation and present at the departments' annual research dialogue.

MPUMALANGA
THE PLACE OF THE RISING SUN

Research Application for Mr Lister Dzikiti - UP

For more information kindly liaise with the department's research unit @ 013 766 5124/5148 0r n.madihlaba@mpuedu.gov.za

The department wishes you well in this important project and pledges to give you the necessary support you may need.

MRS LH MOYANE
(A)HEAD: EDUCATION

01 /06 /2021
DATE