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The development of pre-service teachers' pedagogical content knowledge in electromagnetism

Cornelia Coetzee

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Supervisor: Prof Marissa Rollnick

Co-supervisor: Prof. Estelle Gaigher

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Declaration

I declare that the thesis, *The development of pre-service teachers' pedagogical content knowledge in electromagnetism,* which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Ethics statement

The author, whose name appears on the title page of this thesis, has obtained, for the research described in this work, the applicable research ethics approval. The author declares that she has observed the ethical standards required in terms of the University of Pretoria's *Code of ethics for researchers and the Policy guidelines for responsible research*

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Abstract

This study is concerned with the impact of an intervention on the development of the pedagogical content knowledge (PCK) of pre-service teachers in the topic of electromagnetism, during a physics methodology module. The study is guided by the following question: How is the development of the PCK of pre-service teachers influenced by the explicit inclusion of topic specific PCK about electromagnetism in pre-service teacher education? Explicit instruction about the components of TSPCK as applied to the teaching of electromagnetism was employed as part of the intervention. This qualitative case study, conducted in two phases, was supported by quantitative analysis using the Rasch model. The first phase, involving 14 final-year education students specialising in teaching Physical Sciences, investigated the impact of the intervention, which was determined through pre- and post-assessments using diagnostic questions for content knowledge (CK) and a CoRe tool for PCK. By racking the data in Rasch analysis, the perceived difficulty of items in the CK-tests and CoRe tool could be established and this enabled the researcher to report on specific areas of difficulty in electromagnetism that students encountered both in terms of their own conceptual understanding and in teaching of the topic. The study showed a significant improvement in the CK and PCK of the participants and revealed that the impact on c*urricular saliency* and r*epresentations* was more pronounced than on the other components. Students' persisting inability to identify learners' misconceptions and difficult concepts, was noticeable. In the second phase of the study, three students were observed and video recorded while teaching electromagnetism. The researcher established the extent of students' enactment of the knowledge attained during the intervention and their pedagogical reasoning about their teaching. The study indicated that students were able to enact their PCK to teach towards conceptual understanding integrating the components skilfully, when teaching concepts with which they were comfortable. However, when teaching concepts where their own CK was lacking, their conceptual teaching strategies collapsed. During their first attempts to teach the topic, students did not follow a teaching sequence that lead to conceptual development of ideas, but they were able to adjust the sequencing as a result of this experience.

Key terms: PCK development, pre-service science teachers, electromagnetism

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List of Abbreviations

ANOVA	Analysis of variance
BEd	Bachelor's degree in Education
CAPS	Curriculum and assessment policy statement
CK	Content knowledge
CoRe	Content representation
DIF	Differential item functioning
emf	Electromotive force
FET	Further Education and Training
ICC	Item characteristic curve
MPS	Methodology of Physical Sciences.
MRTEQ	Minimum requirements for teacher education qualifications
PCK	Pedagogical content knowledge
RHR	Right-hand rule
RUMM	Rasch unidimensional measurement models
SD	Standard deviation
TSPCK	Topic specific pedagogical content knowledge
VSR	Video stimulated recall

Chapter 1

Introduction and contextualisation

This study has its roots in science teacher education and it explores the importance of the development of teacher knowledge and more specifically the pedagogical content knowledge (PCK) of the pre-service science teacher. This chapter unveils the context in which pre-service science teachers find themselves in terms of the degree they chose to study, the schools and education system where they have their first pre-service teaching experience and where the study was undertaken. The reasons and a personal rationale for embarking on this study is presented as well as an academic rationale for focussing on the training of the pre-service science teacher. Furthermore, I initiate my argument for situating this study about the improvement of teacher knowledge of pre-service teachers in a framework of PCK. This chapter also presents the research questions, the purpose of the study and a short overview of the methodological approach. The chapter concludes with a summary of the chapter layout of the thesis.

1.1 Introduction

"I can see that my science teacher knows the work, but he/she cannot explain it in such a way that I can understand it." Such a sentence, uttered in exasperation by many science learners, echoes the problematic, dualistic nature of teaching (subject specialist versus teaching specialist), addressed by Shulman at the 1985 annual meeting of the American Educational Research Association (Shulman, 1986). He reported that in research at that time, there was lack of emphasis on teachers' level of subject matter knowledge, which Shulman and his colleagues referred to as "the missing paradigm problem" (p. 6): "The missing paradigm refers to a blind spot with respect to content that now characterizes most research on teaching … (p. 7)". At the other end of the scale, Kind (2009, p. 169) stated what many science teacher educators know: "… a good Bachelor's degree in a science subject …, does not offer *de facto* guarantee that someone will teach a specific subject effectively." Already in 1902 Dewey was cognisant of the fact that the knowledge a teacher had, was quite different from the knowledge a subject specialist had:

> *Every study or subject thus has two aspects: one for the scientist as a scientist; the other for the teacher as a teacher. … For the scientist, the subject matter represents simply a given body of truth to be employed in locating new problems, instituting new researches, and carrying them through to a verified outcome. … The problem of the teacher is a different one. …. how his own knowledge of the subject-matter may assist in interpreting the child's needs and doings, and determine the medium in which the child should be placed in order that his growth may be properly directed. He is concerned, not with the subject-matter as such, but with the subject-matter as a related factor in a total and growing experience. (cited in Sowder 2007, p.162-163).*

The construct of pedagogical content knowledge (PCK) offers the possibility of linking the different knowledge bases of content and pedagogy that were separated in earlier endeavours at teacher education (Veal & MaKinster, 1999). For the purpose of this study, I redesigned an existing subject methodology course to be included in the training of pre-service science teachers with the aim of cultivating a realization of the knowledge bases that make up their PCK and the ability to apply this knowledge in practice.

1.1.1 Clarification of concepts

This section gives operational definitions of terms and concepts used in this study. The list is not in alphabetical order, but I preferred introducing the terms in a logical sequence in which they inform one another.

- FET-phase: The Further Education and Training phase in the South African education system comprising Grades (Gr) 10 to 12.

- Physical Sciences: In this study the term refers to the school subject in the South African school curriculum for the FET phase which comprises Physics and Chemistry topics. These two disciplines are taught and examined separately, but the marks are added and count towards a final mark in Physical Sciences.

- BEd-degree: This is a Bachelor degree in Education. At the university where the study is conducted, students study a minimum of four years to qualify for the degree. During the first three years of study the students study a number of subjects, including education modules, offered by the Faculty of Education, and their elective (major) subjects for which classes are attended in the faculties where the subjects are situated.

For example, students who want to become FET Physical Science teachers will study Physics and Chemistry in the science faculty.

- Methodology of Physical Sciences (MPS): This is a module in the BEd (FET) programme at the university where the study was conducted. The purpose of the methodology module is to equip the students with the skills and knowledge to teach the subject effectively and with confidence in the FET-phase. At the time of the study, the BEd students did methodology modules in the second semester of the third year and the first and fourth terms of the fourth year.

- Teaching Practice: In their final (fourth year), all BEd students enrol for the Teaching Practice module, which takes place during the second and third terms of the fourth year. This module requires that students are placed at schools under the full mentorship of experienced teachers and lecturers. It also includes the presentation of lessons, during which the students are assessed by teachers and university lecturers. Students are exposed to approximately 20 weeks (ten weeks per term) of teaching experience.

- Mentor lecturer: These are lecturers assigned to students during their Teaching Practice. They observe and assess a minimum of two lessons presented by each student and discuss and reflect on the lessons with the student.

- Pre-service teacher: In this study the term refers to a final-year BEd (FET) student specialising in Physical Science, who is also referred to as a student teacher.

- Content representations (CoRes): This is a tool initially developed and introduced by Loughran, Mulhall, and Berry (2004) to capture the PCK of a teacher about a certain curriculum topic in written format. PCK revealed in the CoRe tool is also referred to as *reported* PCK (Mazibe, Coetzee, & Gaigher, 2018).

1.2 The context of the study

It is of great concern that teaching and learning in South Africa are generally not successful. Evidence supporting this statement lies in the performance of South African learners in international tests of educational achievement (Spaull, 2013). In the Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ)-tests for Gr 6 literacy and numeracy, South Africa ranked in the lower 50% of 15 countries for literacy and numeracy – worse than less developed countries such as Tanzania, Kenya and Swaziland. The results of the Trends in International Mathematics and Science Study (TIMSS) are particularly relevant to this research, since TIMSS focusses on the mathematics and science achievement of Gr 4 and 8 learners. However, in 2011 in South Africa, Gr 9 learners wrote the Gr 8 test, because the international Gr 8 test was deemed too difficult for South African Gr 8-learners. Spaull (2012) reported that there was a remarkable improvement in the performance of Grade 9 learners from 2002 to 2011, but,

> *South Africa's post-improvement level of performance is still the lowest of all participating countries, with the average South African Grade 9 child performing between two and three grade levels lower than the average Grade 8 child from other middle-income countries.*(p.4)

In a study conducted on teacher education in South Africa, Arends and Phurutse (2009) reported that "teachers contribute much to learners' educational achievement and should partly be held accountable for poor learner performance …"(p. ix). Since one can conclude that effective teaching is an important prerequisite for learning, teacher education needs to be a major concern for researchers and teacher educators. The following remark by Spaull touches the essence of teacher education and is relevant, not only to mathematics teaching, but to all subjects, including science: "Unless the content knowledge (and thereafter pedagogical content knowledge) of mathematics teachers in poor and rural areas is improved, it will be exceedingly difficult to raise pupil achievement in these areas" (2013, p. 5).

This resonates with Shulman's argument raised about three decades ago (1986), that the knowledge a teacher must be in command of cannot only be content knowledge (CK), neither can it only be general pedagogical knowledge. It has to be an amalgam of both. In an interview with the editors of the *International Journal of Science Education* in 2007 (Berry, Loughran, & van Driel, 2008) Shulman pointed out:

> *So the idea sort of grew slowly, but the emphasis definitely was on this growing sense that emerged from our research that just knowing the content well was really important, just knowing general pedagogy was really important and yet, when you added the two together, you didn't get the teacher* (p. 1274).

In the discussion above, it is evident that a close relationship between CK and PCK emerges. Even though PCK should not be understood as merely a deeper understanding of the content (Geddis, 1993), CK is found to be a necessary, but not sufficient requirement for sound PCK (Davidowitz & Potgieter, 2016; Mavhunga, 2014).

Therefore, it could be agreed that teachers should know more than the subject specialist about the school-related content. They have to make their own CK comprehensible to learners, keeping in mind that each learner brings to class different ideas and a different background. They should be able to do this transformation successfully in situations of different amounts of resources and different class sizes. It becomes clear that to teach a subject requires different kinds of knowledge that are unique to a teacher. It is reasonable to assume that the place where the groundwork for obtaining this knowledge can be done is in pre-service teacher education in accordance with the belief of Friedrichsen et al. (2009).

Teacher education in South Africa is guided by a policy document called the Minimum Requirements for Teacher Education Qualifications (MRTEQ) (Department of Higher Education and Training, 2011, pp. 17,18). According to the policy, a teacher education programme should include subject-focussed disciplinary and pedagogical learning, educationally focussed disciplinary learning and general pedagogical learning. School-based work integrated learning (WIL) also forms an important requirement for the training of student teachers, according to MRTEQ. At the university where this study took place, the subject methodology module and the Teaching Practice module that fourth-year student teachers enrol for encompass key aspects of the requirements by MRTEQ.

1.3 Problem statement

During their school years, student teachers are exposed to numerous examples of teaching, of which many are less than perfect. Lortie, as quoted by Hargreaves (2010, p. 146), called this the “apprenticeship of observation”. As a result, their teacher knowledge is diverse, but often constrained by the examples of the teaching they experienced and remember. This problem is illuminated by the question Grossman (1991, p. 345) posed in relation to teacher education programmes: “How can these deeply ingrained lessons from the apprenticeship of observation be challenged?”

An opinion raised by experts in the study field of PCK is “… one major, if not the main theoretical premise behind studying PCK, is that teachers with higher levels of PCK are better able to help students learn” (Kirschner, Taylor, Rollnick, Borowski, & Mavhunga, 2015, p. 234). If one agrees that a well-developed PCK with its associated skills is an important foundation for good teaching, it is reasonable that teacher educators and researchers on teacher education focus on ways to capture and measure the PCK of student teachers and develop it (Loughran et al., 2004; Mavhunga & Rollnick, 2013; Nilsson & Loughran, 2012; Van Driel, De Jong, & Verloop, 2002). A salient feature of recent literature on different aspects of PCK in science teacher education, is that CK about a specific curriculum topic and its PCK are often studied in tandem. This is in agreement with Shulman's argument that strong CK is a necessary (yet not sufficient) prerequisite for a successful teacher. Topics that researchers used to explore PCK were, for example: the solar system (Henze, van Driel, & Verloop, 2008), electrochemistry (Ndlovu, Mavhunga, & Rollnick, 2014), chemical equilibrium (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008) and organic chemistry (Davidowitz, Potgieter, & Vokwana, 2014).

In support of the notion that the PCK of a science teacher should be captured in the context of a specific science topic (Loughran et al., 2004), Rollnick and others (Davidowitz & Rollnick, 2011; Mavhunga & Rollnick, 2013) argue for the use of the construct topic specific PCK (TSPCK). TSPCK, together with the knowledge of students, knowledge of context and general pedagogical knowledge, feed into the PCK of a teacher.

From my own experience as a teacher and teacher educator, I know that a high level of PCK in one topic does not necessarily mean PCK at the same level in another topic. The question arises: Should a lecturer then, in a science teacher education programme, try to fit in training on all possible topics in the school curriculum? This is not feasible or even desirable, because of time constraints and because curricula change and teachers may face new topics that have not been part of the curriculum in the past. This issue brings to mind the studies done by Mavhunga, Ibrahim, Qhobela, and Rollnick (2016) and Mavhunga (2016), investigating the transferability of PCK from one topic to another. The results of these studies suggest that development of rich PCK in a selected topic during training equips pre-service teachers with the capability to transfer at least certain aspects of their enhanced PCK to other topics.

One of the topics that students and teachers regard as difficult, is electromagnetism (Dori & Belcher, 2005; Sağlam & Millar, 2006). Few studies have been undertaken on the teaching of electromagnetism, even though this is an integral part of school curricula worldwide, including South Africa (DBE, 2011). Consequently, electromagnetism was chosen as the topic on the back of which the development of PCK was studied.

1.4 Rationale

After teaching FET Physical Sciences and Mathematics at a high school in South Africa for six years, I was appointed to teach at a tertiary institution and became involved in teacher education. Currently I am specifically responsible for teaching methodology of physics to student teachers in their third and fourth years. Soon after becoming involved in teacher education, I realised that students have very different ideas about and approaches to what they perceive to be "teaching science". Many of them have the perception that "*teaching is telling"* and "*learning is remembering*", as described by Geddis (1993). During my first years of teaching, observing and assessing the student teachers, I concluded, to my dismay, that "teachers are born, not trained", and this realisation sparked the question: "What then, is my purpose as a teacher educator?" When I started investigating "teacher knowledge" and more specifically "pedagogical content knowledge" in all its facets, I realised that this might be where the answer to my question could be found.

At a workshop for FET teachers on electricity and electric circuits, I saw how understanding dawned upon the attendees as the presenter explained concepts that suddenly became clear to them for the first time, both in terms of their own CK and in terms of their pedagogy of teaching the concept. At the end of the workshop one of the teachers came up to the presenter and asked: "Ma'am, please tell me; what is your magic?" I believe this "magic" is the "teacher knowledge" of the presenter, as described by Shulman, incorporating "qualities and understandings, skills and abilities" and "traits and sensibilities that renders someone a competent teacher" (1986; 1987, p. 4).

From the time a person makes the decision to study to become a teacher, at least four years elapse before this decision becomes a reality. Typically, during those four years, students think about themselves as people who must prove (through tests and assignments) to the lecturers that they know and understand the content of the work they study. When I encounter student teachers in their third or fourth year in the physics methodology class, I see students eager to convince me that they know and understand the physics and/or the general pedagogy, but I seldom see a student who reveals that he/she thinks about ways to transform the content so that someone else may understand it. In the words of Shulman (1986, p. 8), they are "expert students" in the process of transition into "novice teachers". Student teachers should think about CK as something that has to be transformed for teaching rather than something they have to possess for the sake of the knowledge only (Geddis, 1993). Although the development of PCK is certainly an on-going, lifelong process, one of the places to start is during science teacher education (Friedrichsen et al., 2009) and specifically the subject methodology class, where

> *… special consideration needs to be given to ways of helping student teachers recognize and articulate their developing personal knowledge of practice – of which PCK is a powerful element* (Nilsson & Loughran, 2012, p. 701).

As a science teacher educator it is important to me to know that what my students learn in their physics methodology class is relevant and indeed contributes to their development as successful science teachers and that they will be able to enact this in the classroom. In this sense, "successful" means a teacher who knows the subject matter well and understands its place in the curriculum, who knows the learners and understands the way they think and learn, who knows how to guide learners towards understanding difficult concepts and how to establish whether teaching has been effective. All these are embraced by the PCK construct. While most of the above-mentioned elements are vital and should be prioritised in the methodology course work, content knowledge and knowledge of learners are dealt with in other modules during their training

I have reviewed literature about the development of the PCK about topics in the South African FET curriculum and identified the following gaps:

- Few physics topics are included in existing literature about PCK. I encountered studies about PCK of the following physics topics: electric current (Geddis, 1993), forces and electric circuits (Loughran, Berry, & Mulhall, 2006), the solar system and the universe (Henze, van Driel, & Verloop, 2008), electric fields (Melo-Niño, Cañada, & Mellado, 2015), semi-conductors (Rollnick, 2017) and mechanics (Kirschner et al., 2015). Nkosi (2011) chose to focus on the development of the PCK of the sub-topic of electromagnetic induction because of the diverse nature of the topic of electromagnetism. Research about the development of PCK about electromagnetism as a topic has not been reported.

- The very first time many student teachers have the opportunity to put into practice the knowledge and skills they obtained during their training, is in the schools during their Teaching Practice module. The ability of pre-service teachers to transfer to practice their newly attained knowledge and skills has not been investigated adequately (Mavhunga & Rollnick, 2017), especially in physics topics.
- It has not been investigated to what extent the experience final-year education students obtain during the term of Teaching Practice, contributes to the development of the PCK of the students.

The outcome of this study will add to the existing body of knowledge about the development of the PCK of pre-service teachers. A number of case studies have been conducted in this field, but although none of these can be generalised to the population of pre-service teachers, all may eventually contribute to a strong theory about the development of pre-service teachers' PCK. Furthermore, the study will contribute to filling the gap in literature about teaching electromagnetism at school level.

1.5 Purpose of the study

The aim of the study is to conduct an in-depth investigation of the development of the PCK in electromagnetism of student teachers in their fourth year of training. Explicit, purposeful instruction in the teaching of certain aspects of PCK in the context of electromagnetism teaching was employed as part of an intervention during the students' methodology course. The design of such an intervention was guided by the techniques and findings of other researchers in this field (De Jong, Van Driel, & Verloop, 2005; Kaya, 2009; Mavhunga, 2014; Mavhunga & Rollnick, 2013).

Mavhunga and Rollnick (2017) mentioned that not much is known about the extent to which pre-service teachers' PCK revealed in writing and interviews is actually enacted in practice. Therefore, students' ability to translate their PCK into practice was explored when the students were involved in teaching electromagnetism in schools.

Thus, the purpose of this study was two fold:

- to establish whether the CK and PCK of pre-service teachers can be developed through the explicit, purposeful inclusion of knowledge about TSPCK in the methodology class,

- to investigate if and how pre-service teachers translate their learned TSPCK into practice.

1.6 Research questions

Abell (2008, p. 1409) suggested questions for researchers to consider when embarking on studies about PCK: What data do we collect to get a window into teacher knowledge? What value do classroom observations add? When do we collect data on teacher knowledge? What are the critical moments when teachers might display shifts in PCK? I believe that the research questions that guide my study resonate with some of the questions mentioned in Abell's report.

Main question: How is the development of the PCK of pre-service teachers influenced by the explicit inclusion of TSPCK about electromagnetism in pre-service teacher education?

Sub-question 1: What is the impact of an intervention, focussing on the components of TSPCK, on the level of CK and PCK of pre-service teachers in electromagnetism?

Sub-question 2: To what extent is PCK learned during the intervention, manifested in the practice of pre-service teachers as revealed during Teaching Practice?

1.7 Summary of the research design and methodology

This was a multiple case study that took place in two stages. In the first stage, the participants were 14 fourth-year BEd (FET) students enrolled for the Methodology of Physics Sciences module. Initially an assessment of the participants' CK and PCK about electromagnetism in the FET phase was done. Thereafter, an intervention followed in which components of TSPCK in the context of the curriculum topic electromagnetism were explicitly introduced and discussed. This was followed by a second assessment of both the CK and PCK of the students. The CK of the students was assessed by a multiple-choice CK test and the PCK was captured and assessed by the Content Representations (CoRe) tool (Loughran et al., 2004).

Earlier studies implemented an intervention to develop pre-service teachers' TSPCK (Mavhunga, 2012) and the CoRe methodology to track the development of PCK (Nilsson & Loughran, 2012). I deemed it necessary to follow a similar approach to answer the first research question to establish with reliability the improvement of the pre-service teachers' TSPCK, before the subsequent enactment of their PCK was investigated.

During the second stage of the study, some of the participants had the opportunity to teach electromagnetism to Gr 11 learners while doing their Teaching Practice module at different schools. At least 60 minutes of electromagnetism teaching of three of these students were observed and recorded. After they had concluded the teaching of this topic, I conducted a semi-structured interview with each of these students, which included a video stimulated recall (VSR) interview. The data collected during the study was analysed qualitatively, supported by quantitative methods. The full methodological approach and data collection will be explained in Chapter 3.

1.8 Reporting about the study in this thesis.

In this thesis, I report in seven chapters on my study about the PCK development of pre-service teachers. An outline of each chapter is given below:

In the discussion in Chapter 1 I introduce the reader to the background of the study, explaining where it fits into the South African context, and give a rationale for undertaking the study. I also provide the research questions that guide the study.

Chapter 2 presents the literature review under three headings:

- PCK as a construct, focussing on the different models of PCK, how PCK can be captured and assessed and how PCK develops in teachers
- Electromagnetism as a curriculum topic; highlighting the challenges associated with the teaching of the topic
- The conceptual framework of the study; discussing the models used to develop the conceptual framework that supports the study.

Chapter 3 describes the methodology implemented in the study, which was mainly a qualitative approach supported by quantitative analysis using the Rasch model. I also discuss the selection of the sample of pre-service teachers who were exposed to the intervention, the collection and analysis of the data and aspects related to the validity and trustworthiness of the findings.

My discussion in Chapter 4 focusses on the intervention that forms the basis of the first research question. I explain how the intervention was designed and presented. I also elucidate the pre-service teachers' responses to the discussions and events that had taken place during the intervention.

During the first phase of the study, the participants wrote a CK test and a CoRe before and after the intervention. The purpose of the collection of the data was to establish whether the PCK of teaching electromagnetism of the participants developed during the intervention in answer to the first research question. Chapter 5 presents the results obtained from these instruments, a quantitative analysis and a qualitative discussion of the data as well as a preliminary discussion of the findings.

Chapter 6 presents the data collected during the second phase of the study when the enactment of the PCK the three participants attained was investigated in order to answer the second research question. A qualitative analysis and discussion of the video recorded lessons and interviews are given.

Chapter 7 contains concluding remarks about the study. I summarise the findings in answer to the research questions. I discuss the limitations of the study and suggest possible avenues for future research. I conclude with a personal reflection on my experiences during the process of the research.

Chapter 2

Literature review

It is more than 30 years since Shulman introduced the construct PCK and since then it has become an appealing topic for teachers and teacher educators and has been viewed by researchers from many angles. A study with PCK at its core cannot be undertaken without a thorough knowledge of the development of this construct in recent research and considerations of it. In this chapter, I will give a review of the literature that informed and guided my study. Concepts relevant to the study, such as the different models of PCK, how PCK is captured and assessed, how enacted PCK is observed and the teaching of electromagnetism, will be explored. A description and clarification of the conceptual framework in which the study is rooted conclude this chapter.

2.1 Introduction

Since Shulman introduced the term pedagogical content knowledge, it has become an accepted academic construct and has attracted the attention of many researchers involved in teacher development and teacher education. However, different researchers' interpretation of this construct, how it can be defined, captured, measured and developed (if at all) are not always in agreement (Nilsson & Loughran, 2012; Park & Oliver, 2008b). Abell (2008) noticed that the application of the PCK construct in research was inconsistent and incoherent, but concluded that PCK remains a useful idea in science education and that research about this construct can help "solve the dilemmas in science teacher learning" (p. 1413).

Despite the differences in the interpretation of PCK and the limitations it presented, Shulman reiterated its value, as recently as 2015, by stating "one of the motivations for inventing the notion of PCK" (p. 11):

> *Teaching is demanding and difficult mental and physical work that only the most well-educated and mentored professionals can accomplish. PCK is an attribute that teachers develop, and it cannot be found among mere subject matter experts or among*

those who are 'good with kids.' It was really a policy claim about how special teachers were and how they ought to be regarded and respected.

Abell (2008) furthermore underlined that the knowledge of a teacher is more than the sum of the knowledge of the components by which researchers characterise PCK . Every link a teacher makes between the constituent parts adds to the teacher's PCK. Abell, Rogers, Hanuscin, Lee, and Gagnon (2009) also noted that although PCK is one construct, paying attention to the individual components that make up PCK, gives teacher educators a way to scaffold their teaching and develop the PCK of student teachers. Focussing on the individual components also presents a framework to guide the work of researchers. Different researchers employed different frameworks to structure their research and these are discussed in the review. The literature review explores the efforts by researchers in the field to develop and use instruments to capture and portray teachers' PCK. Work done on the development and improvement of pre-service teachers' PCK, which is of particular interest to this study, is also reviewed.

2.2 PCK as a construct

2.2.1 Models of PCK

Being a central part of teacher knowledge, PCK is in itself a complex and intricate construct consisting of distinguishable but inseparable components. Introducing the concept of PCK, Schulman (1986) suggested that the knowledge developing in the mind of a teacher could be categorized into three types of knowledge: (a) subject matter content knowledge, (b) pedagogical content knowledge and c) curricular knowledge. In his paper (1987), advocating a better understanding of a knowledge base for teaching, Shulman suggested a model of *pedagogical reasoning and action,* which referred to "the challenge of taking what [the teacher] already understands and making it ready for effective instruction" (p. 14). This model emphasises the activities that a teacher must go through to lead the learners towards understanding of the content and includes comprehension of the subject matter, planning the transformation of the content, performing teaching activities or instruction, evaluation and reflection.

After the initial conceptualisation of PCK as one of the knowledge bases of teachers, different models of PCK were designed by different researchers to support their research.

One such model by Magnusson, Krajcik and Borko (1999) (building on the ideas of Grossman, 1990), conceptualised PCK for science teaching as having the following components:

- orientations toward science teaching,
- knowledge and beliefs about science curriculum;
- knowledge and beliefs about students' understanding of specific science topics;
- knowledge and beliefs about assessment in science; and
- knowledge and beliefs about instructional strategies for teaching science.

Realising that few of the models exiting before 1999 supported research on the role of PCK in science teacher professional development per se, Veal and MaKinster (1999) developed a hierarchical general taxonomy of PCK and a taxonomy of PCK attributes in the hope that "these organizational frameworks will serve to organize and integrate future research efforts" (p. 1). At the foundation of this general framework is pedagogy in its broadest sense, including aspects such as planning, teaching strategies, evaluation and group work. Veal and Makinster consider general PCK as the first level in their taxonomy being more specific than pedagogy and referring to the PCK in a specific discipline such as science. More distinct than general PCK is the domain-specific PCK focussing on the different subjects within a discipline, for example, Biology, Chemistry and Physics within the science discipline. They introduced topic specific PCK as the level that is most unique and specific and this refers to PCK about teaching topics in a subject, such as teaching electromagnetism as a topic in the physics curriculum. In many instances studies conducted on science teacher professional development indeed focussed on only one particular topic, for example in the work of Henze et al.(2008), Kaya (2009) and Mavhunga and Rollnick (2013). In the last mentioned study, Mavhunga and Rollnick identified five content specific components of TSPCK from which transformation of the CK emerges, namely:

- Learner prior knowledge;
- Curricular saliency;
- What is difficult to teach;
- Representations including analogies; and
- Conceptual teaching strategies.

The link between these five components and the components proposed by Magnusson et al., as mentioned above, is evident and they form an important part of the framework on which the current study is based. Although the Magnusson model is widely cited, researchers studying teacher professional knowledge have not used a single model. The commonalities in the models researchers develop to describe and conceptualise teacher knowledge are striking and one is tempted to seek a comprehensive model that incorporates all the components that researchers find important and necessary to study teacher knowledge. As Park and Chen (2012) phrased it :

> *Although educational scholars have not yet fully reached a consensus on components comprising PCK, they agree that in order for teachers to effectively plan and enact instruction for a certain group of students in a particular context they should be able to integrate the components into PCK in a coherent way* (p. 923).

This lack of convergence in the thinking about PCK necessitated extended discussion about PCK and led to the PCK summit in Colorado, where a consensus model or "a model of teacher professional knowledge and skill [TPK&S] that includes PCK" (Gess-Newsome, 2015) was agreed to (Figure 2-1). The foundation of this model is the teacher professional knowledge base (TPKB), which informs and is informed by topic specific professional knowledge (TSPK). TSPK is not the knowledge of an individual but is shared knowledge held by the profession, also referred to as canonical knowledge. When planning their teaching the science education experts draw from this knowledge base. According to the model, TSPK includes knowledge of instructional strategies, content representations, student understandings, science practices and habits of mind (Gess-Newsome, 2015). The TPK&S model distinguishes between PCK and PCK&S (PCK and skills), because "as PCK grew to include interactive classroom contexts, a tension developed between what teachers knew and what they were able to do" (p. 37). The location of PCK is the classroom; it can be seen in the lesson plans of teachers and is articulated in their reasons for their instructional decisions, while PCK&S is revealed in classroom practice. Gess-Newsome argues that since the knowledge and skill used in the classroom are dynamic and often brief and momentary, these can be captured in interviews with teachers to uncover what they were thinking while they were acting in a certain way and to reflect on their actions. This notion contributed to the methodology of this study and my decision to do interviews after conducting lesson observations.

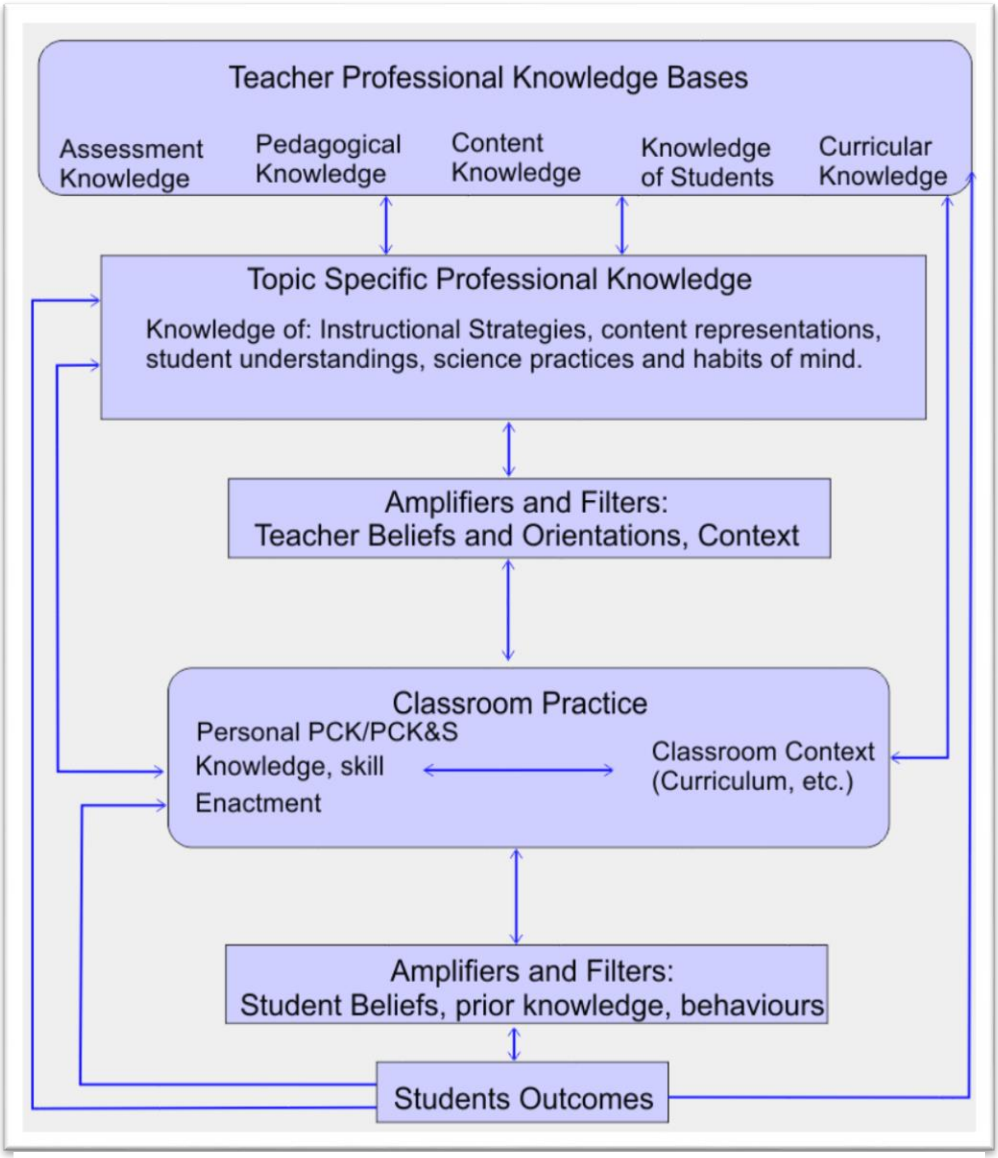


Figure 2-1. Model of teacher professional knowledge and skill including PCK (Gess-Newsome, 2015, p.31)

2.2.2 Capturing and assessing PCK

PCK is an elusive construct that distinguishes a teacher from a subject specialist. However, teachers do not often articulate this knowledge in their normal everyday discourse, because there is no reason or expectation to explicate their pedagogical reasons for teaching the way they do and because they are often unaware of this knowledge they possess (Loughran et al., 2004). Furthermore, no two teachers, however experienced, will have the same PCK about a specific topic they teach.

Teacher educators and researchers realise that PCK is not only an observable, externally noticeable construct, but to a greater extent an internal construct (Baxter & Lederman, 1999) which necessitates multiple methods of investigation. Many techniques and methodologies have been used to explore teachers' PCK, for example collecting data through classroom observations, written reflections, lesson plans, interviews and written portrayals of PCK (Friedrichsen et al., 2009; Nilsson, 2008; Park & Oliver, 2008b). Kind (2009) argues that knowing how to represent a science teacher's PCK and understanding how it develops "will contribute to our understanding of what high quality science teaching looks like" (p. 171). It is therefore not surprising that the following question seems to be prominent in the work of researchers in the field of teacher knowledge and PCK: Can PCK be effectively captured and portrayed? (Loughran et al., 2004; Rollnick & Mavhunga, 2016)

Loughran et al. (2004) developed valuable and practical instruments for capturing and portraying PCK namely Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PaP-eRs). A CoRe is a tool to access the knowledge a teacher has about a certain science topic and the teaching of that topic. PaP-eRs are always linked to CoRes and provide a window into a teaching and learning situation of the specific topic addressed in the CoRe (Loughran, Mulhall, & Berry, 2008). The relationship between CoRes and PaP-eRs are best understood through the explanation given by the developers themselves: "A CoRe is a holistic overview of teachers' PCK related to the teaching of a given topic and the associated PaP-eRs are narrative accounts designed to purposefully offer insights into specific instances of that PCK" (Loughran et al., 2006, p. 25).

The CoRe tool developed by Loughran et al. consists of eight prompts, organised in tabular format, that elicit teachers' understanding of specific subject content and the teaching thereof (e.g. knowledge of important ideas in the content, knowledge of common misconceptions, how to sequence the teaching of the content and how to assess understanding) (Loughran et al., 2004). The "big ideas", which are the headings of the columns in the instrument are key ideas or main concepts that underpin the understanding of the particular science topic and the rest of the prompts are completed with reference to these big ideas. Thus, CoRes constructed by an individual give a qualitative picture of the person's knowledge about the content and the teaching of a specific topic.

The purpose of CoRes is to capture and portray teachers' knowledge across a specific topic by analysing their responses to the prompts in the tool (Loughran et al., 2004). A very significant property of the tool is that it focusses on and reveals both the CK of the teacher and some of the teacher's pedagogical reasoning which underpins the notion of PCK. Researchers perceive the CoRe tool as a useful instrument to capture and assess teachers' and pre-service teachers' PCK (Chordnork & Yuenyong, 2014). CoRes are often used as a tool to track the development of PCK before, during and after an intervention (Nilsson & Loughran, 2012; Rollnick & Mavhunga, 2016). Bertram (2012) undertook a study where the participating science teachers completed individual CoRes with the purpose of accessing and revealing their hidden PCK. All the participants "noted the intrinsic worth of creating a CoRe for their own professional knowledge of practice" (p. 22). Another application is seen in a study by Qhobela and Moru (2014) in a context where science teaching is dominated by traditional teacher-centred strategies. CoRes were introduced as a tool to assist Physics teachers to analyse the content and pedagogy of a topic with the purpose of guiding them to design and implement lessons that support learners' construction of new knowledge.

A notable parallel can be seen between the prompts in the CoRe tool developed by Loughran et al. and the five components of TSPCK, listed before, and this leads to an adaptation of the CoRe (Figure 2-2) by Rollnick and Mavhunga (2016) to coincide with these five components.

	Big idea 1	Big idea 2	Etc.
A. Curricular saliency			
A1. What do you intend the learners to know about this idea? A2. Why is it important for students to know this? A3. What concepts need to be taught before teaching this idea? A4. What else do you know about this idea (that you do not intend learners to know yet)?			
B. What makes a topic easy or difficult to understand			
B1. What do you consider difficult about teaching this idea?			
C. Learner prior knowledge			
C1. What are typical learners' misconceptions when teaching this idea?			
D. Conceptual teaching strategies			
D1. What effective teaching strategies would you use to teach this big idea? D2. What questions would you consider important to ask in your teaching strategy?			
E. Representations			
E1. What representations would you use in your teaching strategy?			
Additional questions not linked to a specific component			
What ways would you use to assess learners' understanding? What other aspects of planning for and teaching this idea would you reflect on?			

Figure 2-2: Template of the adapted CoRe (Rollnick & Mavhunga, 2016)

Many researchers have attempted quantitative measurement of teachers' PCK and related aspects. It was found that the development of PCK is dependent on a teachers' level of CK (Henze & Van Driel, 2015) and that, in teacher development, PCK improves as the CK of the teacher develops (Rollnick, 2017). However, apart from a teacher's level of CK, other teacher characteristics can influence PCK, such as beliefs, cognitive abilities and motivation. Kirschner et al. (2015) contends that such characteristics should be controlled in measurements of PCK and its effect on learner outcomes

Yet, because of the undisputable link between CK and PCK, researchers realised that it was valuable to measure CK of a specific topic as well whenever an instrument to measure PCK was developed or used. For this purpose they developed instruments to measure the CK and PCK of teachers on specific topics in an objective and reliable way (Jüttner, Boone, Park, & Neuhaus, 2013; Mavhunga & Rollnick, 2011). However, Park and Suh (2015) argued that, although it may be considered ideal to develop different measures for all possible different topics, it would be unrealistic and would not have much meaning for comparisons with other measurements. Consequently, these researchers developed a PCK rubric (using a four point rating scale) that is used to measure PCK as reflected in observations and interviews and can be adapted for any topic. In other words, this is a quantitative instrument for assessing teachers' PCK as revealed in practice or in written format and is often used in studies (Mavhunga, 2012; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008).

Valuable guidelines for the assessment of PCK enacted during teaching through the use of rubrics are found in the work of Chan, Rollnick, and Gess-Newsome (in press). They argue that the researcher should possess sophisticated PCK and use evidence from exemplary practice when assessing PCK. The rubric designed and used for scoring the enacted PCK (revealed in paper-and-pencil tests, interviews and/or observations) should have clear descriptors for the performance levels. They further argue that a teacher's pedagogical reasoning cannot be accessed through observations only and suggest VSR interviews to access a teacher's reflection about his/her teaching.

2.2.3 Development of PCK

Other questions, salient in PCK research (Mavhunga & Rollnick, 2013; Nilsson & Loughran, 2012) and relevant to my research questions, are: Can PCK be taught by an expert to a novice? Can PCK about science topics be developed in a student teacher who has never taught science before? In literature, there is no clear distinction between the phrases "development of PCK" (to introduce and embed PCK in the case of novice teachers) and "improvement of PCK" (to advance to a level of higher quality PCK in the case of experienced teachers). Van Driel et al. (2002) and Nilsson and Loughran (2012) explored the *development of PCK of pre-service teachers,* whereas Henze et al. (2008) investigated the *development of experienced science teachers' PCK* and Mavhunga (2014) explored the *improvement of PCK and CK in pre-service science teachers.* In this study, I am considering the development of the personal PCK of pre-service teachers during an intervention in the methodology course and the enactments and possible improvement thereof during their first formal teaching experience.

It seems reasonable to expect that, since quality PCK is an important attribute of a good teacher, teacher educators should strive to develop this in teacher education programmes. Grossman (1990) considered four aspects that can contribute to the development and improvement of PCK: (a) disciplinary education, (b) observation of lessons conducted by others, (c) teaching experience and (d) courses or workshops during training. In literature about the development of PCK, researchers investigated the impact of one or more of these aspects. Nilsson (2008) considered experience and self-reflection by student teachers on their own teaching as ways to stimulate better understanding of what science teaching and learning entails. Hence, she investigated the effect of these aspects in the development of the students' PCK. Van Driel, De Jong and Verloop (2002), Nilsson and Loughran (2012) and Mavhunga and Rollnick (2013) focussed on the contribution of workshops and interventions during the teacher education programme in improving the PCK of pre-service teachers.

Although in the literature mentioned above the emphasis was on the development of the PCK of pre-service teachers, there are also studies that investigate the improvement of the PCK of experienced teachers. It was found that an in-service workshop on a specific topic, giving teachers guided experience in presenting an experimental course, did indeed improve their PCK (Van Driel, Verloop, & de Vos, 1998). Henze and others (2008) investigated the development of the PCK of experienced teachers while following their teaching of new curriculum content for three years and reported how different types of PCK emerged.

As with the assessment of PCK, many studies on development of PCK with the focus on one specific curriculum topic have been reported. Examples are studies on improving the PCK of chemical equilibrium in pre-service teachers (Mavhunga & Rollnick, 2013; Van Driel et al., 1998) and on developing PCK of models of the solar system and the universe (Henze et al., 2008). The question arises whether it is sufficient to develop the PCK of teachers in one topic, assuming that they will have the capability to transfer their enhanced PCK to other topics.

Enlightening studies on the transferability of PCK were done by Qhobela, Ibrahim, Mavhunga, Rollnick (2014) and Mavhunga (2016). They investigated whether pre-service teachers could transfer the PCK they have developed in one topic under lecturer guidance, to another topic. They used the TSPCK framework (Mavhunga, 2012; Mavhunga & Rollnick, 2013) and assessed the transferability of PCK for the five components of the framework: knowledge of curricular saliency, learners' misconceptions and prior knowledge, knowledge of what is difficult to teach, the representations to use, and knowledge of the conceptual teaching strategy to employ. Qhobela et al. (2014) found that students could best transfer their knowledge of "curricular saliency" and "what is difficult to teach" to another topic. However, "knowledge of misconceptions and learner prior knowledge" was poorly transferred. As such, one can conclude that TSPCK was not fully transferred.

Mavhunga (2016) investigated the transferability of PCK in terms of the construct pedagogical transformation competence (PTC) through which TSPCK in a specific topic develops. In her study, pre-service teachers demonstrated their ability to transfer their PTC to develop TSPCK in a new topic. These studies have implications for teacher education, because one could argue that if student teachers develop PCK at an adequate level in one or two topics, they will be able to transfer that (or at least certain components) during their practice to the other topics they need to teach.

2.2.4 Knowledge and practice - Enacting PCK

Since teaching is an action, it is important that studies about PCK venture into the exploration of the relationship between knowing (CK and PCK) and acting (Henze & Van Driel, 2015). Baxter and Lederman (1999) emphasised the importance of the translation of PCK into action. They remarked that many researchers were of the opinion that teachers' actions are a better representation of their knowledge than self-reported displays of their PCK. Shulman (2015) subscribed to this notion, saying that:

> *It simply doesn't make much sense to be reflective about practices you're not skilled at performing, and teaching IS a form of skilled performance*. (p. 10)

To understand the said relationship between knowledge and practice, Alonzo and Kim (2016) used the constructs *declarative PCK*, which includes, but is not restricted to paper- and pencil methods to capture PCK and *dynamic PCK* which refers to instances where declarative PCK is being reflected during teaching. They noticed that "teachers' dynamic PCK appeared to rely heavily on their declarative PCK" (p.21). A similar distinction was made by Mazibe et al. (2018), using the constructs *reported PCK* and *enacted PCK* . These researchers found that teachers often report richer PCK than what they enact in the classroom. Park and Suh (2015) highlight the importance of establishing how the PCK of teachers who "enact quality teaching" differs from those who do not and by which means and devices teachers translate their PCK into practice.

A model that effectively illustrates the relationship between knowledge and practice was designed by Smith and Banilower (2015) (Figure 2-3). The model indicates that research on student thinking, the impact of instructional practices and assessment strategies, shapes canonical PCK and that, through the act of teaching, personal PCK is shaped. In the words of the authors, "canonical PCK becomes personal through application - preparing to teach, teaching or reflecting on teaching" (2015, p. 90). However, the model does not show how canonical PCK becomes part of the knowledge base of a novice teacher so that, through the act of teaching, it can become part of the personal PCK of the teacher.

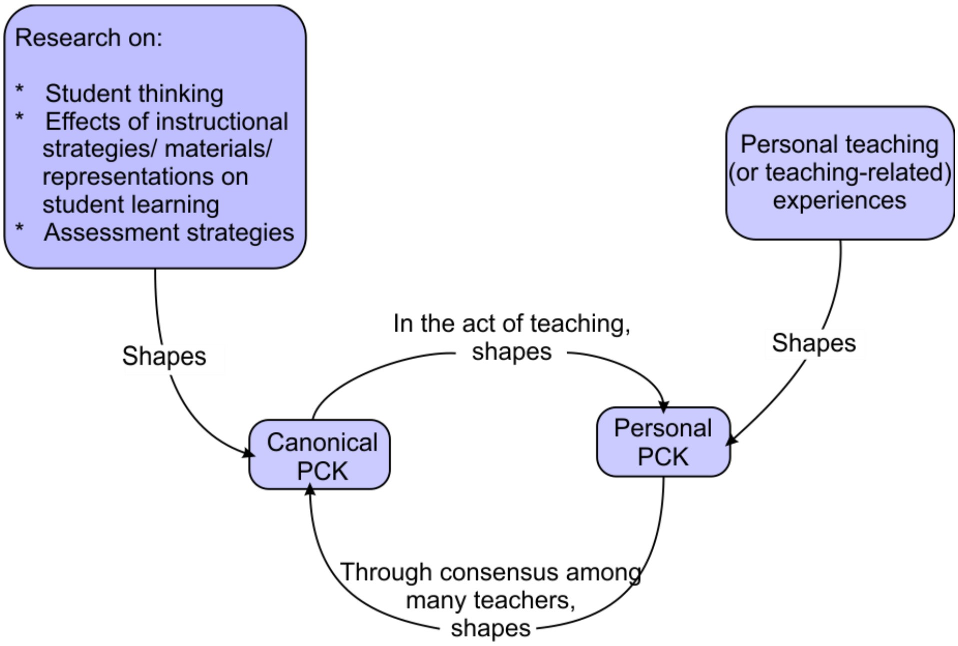


Figure 2-3: Relationship between knowledge and practice. (Smith, Banilower, 2015)

Existing literature (De Jong et al., 2005; Loughran et al., 2008; Mavhunga, 2014); Qhobela et al. (2014); (Van Driel et al., 2002) indicates that researchers believe that they impart exemplary PCK (that is, canonical PCK) to the participants through interventions during course work and workshops. However, it is not always clear whether the improvement of PCK indicated in these studies gravitated to personal PCK of the participants that could be enacted during teaching. The diagram further elucidates that teaching experiences also contribute to and shape personal PCK. This corresponds with the view of Van Driel et al. (1998) who identified "teaching experience as a major source of PCK" (p. 673). The question to be asked now is: Will learned PCK inform or change practice? In other words: Will learned PCK become personal PCK to be enacted during teaching? This question is encompassed in the second research sub-question of this study.

2.3 Electromagnetism as a curriculum topic

Electromagnetism is an important component of the Gr 11 and 12 curriculum in South Africa (Department of Basic Education, 2011) as in many other countries and generally regarded as a difficult topic to teach and to understand mainly because of its abstract nature (Dori & Belcher, 2005).

2.3.1 Misconceptions and learner difficulties in electromagnetism

A recent study by Jelicic, Planinic, and Planinsic (2017) on high school learners' reasoning about electromagnetism, confirmed that learners find the topic challenging and that they have deeply rooted misconceptions and use unscientific models to explain electromagnetic phenomena. Maloney, O'Kuma, Hieggelke and Van Heuvelen (2001) developed a Conceptual Survey of Electricity and Magnetism (CSEM) to identify some alternative conceptions learners have about electricity and magnetism. The items designed for this survey together with the items in the diagnostic test developed by Sağlam et al. (2006) are potentially useful for the design of CK measuring instruments.

An attentive educator knows that learners often make recurring mistakes and that not all of these can be regarded as misconceptions. Luneta and Makonye (2010) distinguish between errors and misconceptions by defining an error as an inaccuracy that learners can often easily correct themselves and is usually not persistent but misconceptions as ideas that "are intuitively sensible to learners" (p. 36), which are resistant to change and can be masked in correct answers. These are often the result of the "deeply rooted conceptions and ideas that are not in harmony with science views" (Duit & Treagust, 2003, p. 671) with which learners come into science class. A basic misconception learners have about magnetic fields was documented by Guisasola, Almudi, and Zubimendi (2004) namely that "the existence of the magnetic field is due to that of field lines" (p.456) and that the field lines are the mechanisms through which the magnetic forces act. Another misconception that influences learners thinking about many aspects in electromagnetism is the "magnetic poles are charged" idea, which is linked to the general confusion between electric and magnetic fields (Maloney, 1985; Maloney et al., 2001). This may lead learners to believe that magnetic poles exert forces on charges, whether the charges are moving or not (Jelicic et al., 2017). Maloney et al. also reported on learners' problem with interpreting the "rate of change in the magnetic flux" as opposed to just the "change in magnetic flux". Zuza, Almudí, Leniz, and Guisasola (2014) remarked that many students see magnetic flux as the “flow” of the magnetic field, which can be associated with Sağlam and Millar’s (2006) observation that learners think that magnetic field lines indicate the “flow” of the magnetic field. This may be related with the confusion learners have between the mere presence of magnetic flux and the change in magnetic flux as observed by Mauk and Hingley (2005). Sağlam and Millar also added to the list of learner difficulties the challenges some learners have related to the interpretation of three-dimensional situations presented in a two dimensional diagrams. Knowing about and understanding these learner difficulties and possible misconceptions in electromagnetism are important components of a teacher’s PCK about this topic. Without such knowledge a teacher is regarded as having limited PCK (Park, Jang, Chen, & Jung, 2011).

2.3.2 Teaching electromagnetism

In the South African school curriculum (Department of Department of Basic Education, 2011), basic concepts about magnetism and magnetic field are covered in Gr 10. Electromagnetism is introduced in Gr 11 and is broken down into two main topics; the magnetic field around a current-carrying conductor and Faraday’s law. Magnetic flux is not explicitly introduced as a separate topic, but is addressed under Faraday’s law. In Gr 12 the curriculum prescribes the study of generators and motors and alternating current under the heading of electrodynamics (see Appendix A).

As far as the teaching of electromagnetism is concerned, there is a paucity in literature, even though students’ challenges with the topic are well documented (Jelicic, Planinic, & Planinsic, 2017; Sağlam & Millar, 2006; Zuza, Almudí, Leniz, & Guisasola, 2014). The impact of multimedia on teaching electromagnetism in an introductory course at university level was assessed by Stelzer, Brookes, Gladding, and Mestre (2010), but studies about the teaching of the topic at school level did not receive much attention.

Dori and Belcher commented that “unlike mechanical phenomena, such as motion, acceleration and impetus, which can be sensed visually and sometimes also vocally and through touching, electromagnetism is in a realm of physics that is not covered by any one of the five human senses” (2005, p. 249). They presented this aspect as an important reason for the difficulties students of all ages experience when trying to understand electromagnetic concepts. Thus, helping learners to understand electromagnetism indeed necessitates a unique pedagogy and a clear understanding of the topic. It therefore seems appropriate that the PCK of this topic should be investigated.

2.4 Conceptual framework for this study

It became evident during my study of the literature on PCK that, through research about the teaching and learning of specific topics, a knowledge base (TSPK) has been established for science teachers that can be called canonical, because it is used as a benchmark and a standard of exemplary PCK for those topics. When researchers design interventions, workshops or course work for developing and/or improving the PCK and skills of science teachers they draw from this knowledge base. This is also the yardstick against which researchers and teacher educators can gauge the PCK of teachers. The PCK Summit consensus model described by Gess-Newsome (2015) supports the framework of my study. I will, however, use the five components of TSPCK (Mavhunga, 2012) that align closely with the description of TSPK in the model to frame the design of my study. These five components of TSPCK also align with the CoRe tool and therefore link the instrument effectively with this framework.

I adapted the framework of Smith and Banilower (2015) discussed in §2.2, to include reasoning that emerged from the consensus model and from Mahvunga's TSPCK framework to develop a conceptual framework that supports my study (Figure 2.4). The canonical PCK is described by the five components of TSPCK as related to the teaching of

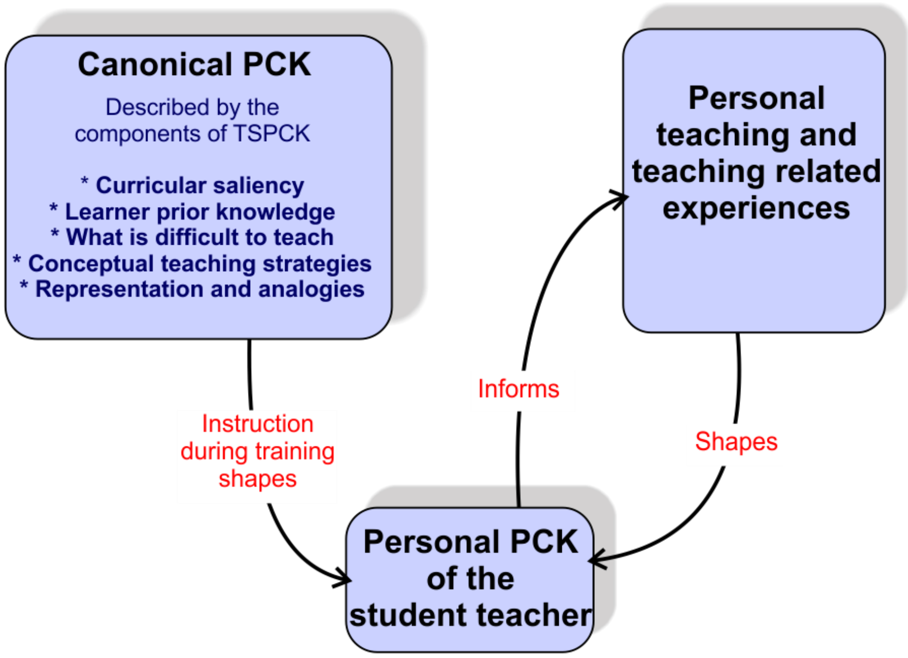


Figure 2-4: Conceptual framework for this study

electromagnetism and captured in the expert CoRe for Gr. 11 electromagnetism (see §3.5.2.1).

Through instruction, for instance during pre-service teacher education, the canonical PCK shapes the personal PCK of the student teacher. The definition of personal PCK by Gess-Newsome (2015, p. 36) is adopted in this study:

> *Personal PCK is the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection on Action, Explicit).*

During teaching practice, the student teacher also gets the opportunity to employ the newly developed or enhanced PCK and skills in actual teaching situations, which in turn shape the personal PCK of the student teacher. Two of the three arrows in the diagram (Figure 2-4) are the objects of investigation of the current study and link to the research questions. The arrow that indicates feedback from the teaching experiences to the personal PCK falls outside the scope of the study.

2.4.1 Components of TSPCK

Curricular saliency

Knowledge about the curricular saliency of a topic enables a teacher to select the concepts that are key to the understanding of the topic. In the constructivist classroom the focus will be on the conceptual development of these key ideas (Haney & McArthur, 2002) as opposed to the mere basic, procedural skills. Furthermore, this component entails knowledge of the sequence of instruction of concepts within a topic and how different topics relate and build on one another logically. This includes knowledge of what the pre-concepts of a particular key idea are and understanding of the significance of the topic in the curriculum (Rollnick et al., 2008). Knowledge of this component enables a teacher to know how much time to spend on the teaching of the key and subordinate ideas.

What is difficult to teach?

Effective transformation of CK requires awareness of concepts that need dedicated attention and interventions when teaching the key idea. A teacher who is cognisant of the topics or concepts that learners usually find difficult to understand will design strategies dedicated to transform these ideas for comprehension by learners (Mavhunga, 2012). This also relates to a teacher's awareness of how to vary the time spent on different concepts.

Learner prior knowledge

Knowledge about this component enables teachers to relate their teaching to what learners already know (Van Driel et al., 2002), either from previous instruction or personal experiences (Duit & Treagust, 2003). The prior knowledge of learners about many science topics include, apart from the ideas they normally understand correctly, typical alternative ideas and misconceptions that are often documented in research literature (also see §2.3.1)

Representations

This component refers to knowledge of representing the subject content in ways that support the conceptual development of the key ideas; these include analogies, demonstrations, diagrams, models and computer simulations. A teacher's PCK about a topic is apparent in this component when the teacher applies representations effectively to transform the content to make it accessible to learners (Shulman, 1986), while being mindful of the limitations of certain representations.

Conceptual teaching strategies

This component refers to a teachers' ability to design instruction strategies and topic-specific activities while keeping in mind the difficulties and misconceptions learners have, knowing useful representations and questions to ask to support conceptual understanding of the key idea. According to Mavhunga (2012) this component proves to be the most difficult to develop and to assess, because it encompasses knowledge, competence and fruitful integration of all the above-mentioned components.

2.5 Summary

Science educators and learners alike know that a good science teacher is characterised by more than sound CK and therefore have an intuitive interpretation of what PCK entails even though they may not have heard of the construct before. However, to describe the body of knowledge that defines PCK proved to be a daunting task. In this chapter, I reported on some of the most prominent models of PCK that emerged from the work of science education researchers. Three of these models were used to support the framework of the current study: the consensus model (Gess-Newsome, 2015), the TSPCK model (Mavhunga, 2012) and the model developed by Smith and Banilower (2015), which describes the interaction between knowledge and practice.

As mentioned by Rollnick (2017), there is disagreement whether personal PCK and canonical PCK can be distinguished from one another. In the current study the distinction between the two made in the model of Smith and Banilower proved useful, because it is assumed that the PCK of the participants in the study is not at the same level, may not develop similarly and may not reach the level of PCK held by the profession.

In Chapter 3 I will describe how the conceptual framework of the study informed the research methodology used to establish how the PCK of student teachers developed and how they enacted their PCK in their first teaching experiences of electromagnetism.

Chapter 3

Methodology

In this study, I am investigating the effect of explicit instruction in TSPCK components on the development of the personal PCK of pre-service teachers about the teaching of electromagnetism. I further investigate how they enact their PCK during their first formal teaching experiences. To achieve this I designed an intervention and used instruments to follow the progress in the development of the participants' PCK. In this chapter I explain my paradigmatic stance that determined the approach I followed to address the research questions. I also clarify the methodology I followed and elucidate the considerations I took into account to enhance the trustworthiness and reliability of the study.

3.1 Introduction

During my years of experience in teacher education, I became aware of the fact that student teachers respond very differently to my teaching and mentoring. During their training they construct different realities about what science teaching is, how learners learn and how they plan to teach. I also realised that the realities they create are greatly influenced by the experiences they had during their own school years. Therefore, eliciting students' pedagogical reasoning about teaching electromagnetism and following its development and improvement required careful planning.

This was a multiple case study that took place in two stages. Stage one, involving 14 students, set out to establish the impact of an intervention on the CK and PCK of the participants. The intervention focussed explicitly on the components of TSPCK as these pertain to the teaching of electromagnetism. Pre- and post-data were collected through a multiple-choice CK test and a CoRe tool and were analysed both qualitatively and quantitatively. The second stage involved the observation of three students teaching electromagnetism in schools, with the objective of establishing their ability to enact their newly attained TSPCK. Data were collected by video-recording the lessons and conducting interviews with the student teachers. Analysis of the data required careful consideration of aspects, including my own perceptions and biases that could influence my interpretation of the outcomes. In this chapter, I discuss the reasoning behind and implementation of my research design and methodology.

3.2 Research paradigm and approach

My assumptions about the nature of reality (ontology) and how it can be known (epistemology), determined the approach to my study, the type of instruments I used, the kind of data I collected, the way in which I collected and analysed it and the way I interpreted the data (Cohen, Manion, & Morrison, 2013). It is therefore essential that I reveal my view about the reality I am investigating to account for the methodology I employed.

My epistemological stance is post-positivistic, because I believe "that social reality is constructed and that it is constructed differently by different individuals" (Gall, Borg, & Gall, 1996, p. 19), which is reinforced by my experience that pre-service teachers respond differently to my instruction and to their first teaching experiences. Furthermore I believe that "the constructed reality does not exist in a vacuum, but is influenced by context" (Nieuwenhuis, 2007a, p. 65), which is supported by my own experience as a teacher and teacher educator.

I approached my study from an interpretive paradigm, as described by Gall et al. (1996), Nieuwenhuis (2007a) and Cohen et al. (2013), which is consistent with my post-positivistic epistemology. In this study, my endeavour was to understand the development of pre-service teacher's PCK and to investigate how PCK can be improved by explicit instruction in the methodology class. Because PCK is a construct that is embedded in the mind of a teacher, it is often tacit and hidden inside an individual, and it is therefore necessary, in the words of Cohen et al., that "efforts [should be] made to get inside the person and to understand from within" (2013, p. 17). This is one of the key enterprises in the interpretive paradigm. To achieve this, the researcher needs to be closely involved with the participants and their actions. To this end I designed an intervention where students were guided explicitly to think about their teaching of electromagnetism in terms of the five knowledge components of TSPCK. I expected them to write CoRes on the topic of electromagnetism at certain stages during the research in order to ascertain their thinking about teaching the topic. They also had the opportunity to implement their ideas in mock and real teaching situations while I observed them. I interpreted their efforts with the help and input of other subject and science education experts.

To appreciate a person's PCK and the development thereof, the data gathered had to be informative, mostly communicated through words and sentences for the researcher to explore and interpret. According to Leedy and Ormrod (2005), this calls for a qualitative approach and more specifically a case study. This study strived towards an understanding of how the pre-service teachers recognise, appreciate and transform their own PCK (as the phenomenon under investigation). As such it complied with one of the central characteristics of case study research as indicated by Nieuwenhuis (2007b) and Gall et al. (1996), namely an in-depth study with the focus on each case to understand how each participant makes meaning of the phenomenon in its natural context.

It is often said that case studies have limited generalisability since a case (or a few cases) is not a representative sample of a population. Whereas the purpose of studying a representative sample in quantitative studies is to generalise towards a population, the concern of case study research is to understand the case being studied and to extend and generalise a theory (Cohen et al., 2013). To achieve this, one should take the suggestion of Gall et al. (1996) into consideration that a case study should be designed in such a way that the findings can be applied to other cases typical of the phenomenon. Then, by building up sufficient case studies an argument towards generalization can eventually be constructed. The current study can indeed contribute in this manner, because the case I will be investigating (PCK development of pre-service science teachers at a South African university) is typical of other studies (Kaya, 2009; Mavhunga & Rollnick, 2013; Nilsson, 2008; Van Driel et al., 2002). These studies were undertaken by researchers who had already contributed to the theory of PCK as underpinned by the model of teacher professional knowledge and skill (Gess-Newsome, 2015), described in the literature review.

Even though the main methodological approach of this study was qualitative, the findings in answer to the first sub-question, were supported by quantitative analysis using the Rasch model which will be described in detail in §3.6.

3.3 Sample selection

The participants in this study were final-year education students at a university in South Africa. These students were enrolled for the BEd (FET) degree specialising in Physical Sciences for the FET phase (Gr 10-12) and attended classes in their elective modules (major subjects) together with mainstream BSc students in the Science faculty. By the time they started their final year, they had completed a full first year of Physics, Chemistry and Mathematics, a second year of Physics or Chemistry together with Mathematics and a third year of one of Physics, Chemistry or Mathematics. They had also completed modules focussing on generic education concepts and principles running over three years.

The study was conducted in two phases. For both phases, my sampling was pragmatic and convenient. Sixteen students were enrolled for the Physical Sciences methodology module. All 16 students gave consent that the assessments done for the module could be used as data for this study. From this group I collected a baseline CK-test (pre-CK test), an individual Core (pre-CoRe), and a post-CK test and post-CoRe after the intervention. However, two students did not write the second CK and CoRe assessments and were therefore excluded from the study. Thus for the first part of the study I had 14 participating student teachers. The instruments and data collection will be discussed in other sections of this chapter.

Three students constituted the sample for the second phase and were selected as described below. During their Teaching Practice modules, which ran over the second and third terms of their final year, the students could choose which of their elective subjects (Physical Sciences or Mathematics) they preferred to teach in each term. Since electromagnetism is taught in term three in government schools as prescribed by the curriculum document (Department of Basic Education, 2011), only those students who chose to teach Physical Sciences in term three could participate in the second stage of my study. Seven students chose to teach Physical Sciences and were allowed by their mentor teachers to teach Gr 11 classes. I obtained permission from the school principals, the mentor teachers and the students to observe and video-record the students' lessons and involve them in my study. However, I managed to collect enough data in terms of recorded lessons of only three students. These students constitute the sample for the multiple case study on which I embarked to answer the second research question of the study.

I introduce the participating students for both phases in Table 3-1:

Column 1: The names are codes I used to identify the students.

Column 2: Gender

Column 3: An indication whether English was the primary language of the participants. It should be kept in mind that the intervention was conducted in English.

Columns 4 to 6: Highest qualification in the three elective subjects: Physics (P), Chemistry (C) and Mathematics (M). The number in the subject column indicates the undergraduate level (number of years) at which the subject was passed.

Column 7: Students participating in the second phase of the study.

Columns 8 and 9: These columns indicate the primary language of the participants in the second phase of the study and the language in which they taught (language of instruction).

Table 3-1: Profile of participating students

Student	Gender	English primary language?	P	C	M	Sample phase 2	Primary language	Language of instruction
AW	M	No	2	1	3			
BM	M	No	1	2	3			
DK	M	No	3	1	2			
HD	F	No	2	1	3			
HS	M	No	2	1	3	✓	Afrikaans	Afrikaans
JD	F	No	2	1	3			
KM	F	No	2	1	3			
LM	M	No	3	1	2			
MS	F	No	1	3	2			
MW	F	No	2	1	3			
NL	F	No	2	1	3	✓	SiSwati	English
TM	M	No	3	1	2			
VS	M	No	2	1	3			
NB	F	Yes	3	1	2	✓	English	English

3.4 Research design

At the beginning of their fourth year methodology module participants wrote a pre-test and CoRe to determine the level of their content knowledge and PCK about the topic. They were informed about this test in advance.

Immediately after the pre-test an intervention followed, which formed part of the physics methodology module, with a duration of six weeks. The intervention is described in more detail in Chapter 4 and a summary of the intervention can be viewed in Appendix C. The focus was on explicit communication and instruction about the five knowledge components of TSPCK from which transformation of content emerges (see conceptual framework, §2.4 p.27) and how it applies to the teaching of electromagnetism. The canonical PCK about teaching electromagnetism is represented in an expert CoRe (Appendix H), which was constructed for the purpose of the study by experienced science teachers and science teacher educators. As such, the expert CoRe served as an example of exemplary TSPCK.

To track students' understanding of the components during the intervention, they were expected to construct CoRes (mid-intervention CoRes) for key ideas they selected from magnetism, electromagnetism or electrodynamics in the Gr10 to 12 curriculum. They had to use these to plan lessons and present these to peers, giving them the opportunity to employ and internalise the newly learned TSPCK.

At the end of the six weeks the participants wrote the CK test again and constructed a CoRe to establish the impact of the intervention on their knowledge of the content and the five components of TSPCK as these pertain to electromagnetism. The post-CK test was the same as the pre-test. Analysis and interpretation of this data answered research question one.

During the second phase of the study when the participants did their teaching practice in schools, I observed and recorded at least 60 minutes of teaching of electromagnetism by each of three students. The lessons observed were analysed to establish whether the students were able to employ the knowledge they had gained during the intervention. The question may be asked why it was necessary to observe lessons: Wouldn't it suffice to scrutinise the planning of these lessons and the CoRes written about the topic? Teachers' PCK is often not well articulated by the teachers themselves. It manifests in the way the teacher performs during the teaching of a lesson and the way she reacts to learners in the teaching situation. In the words of Park and Oliver (2008a, p. 813): "PCK can be expressed only when teachers deal with the transformation of subject matter for a specific group of students in a specific classroom, and in this regard it is closely linked to teachers' actual teaching performances and student's learning." As such, I considered the lesson observation an important contribution to the data for the study.

After the last lesson observations, selected sections from the recordings were discussed with the participants during video stimulated recall (VSR) interviews. The VSR interviews were followed by a semi-structured interview prompting students to discuss their perceptions about teaching electromagnetism. I refrained from mentoring the students during these interviews, so that I could elicit their untainted perceptions and pedagogical reasoning about their own teaching of electromagnetism. Analysis and interpretation of the lesson recordings and interviews led to answering research question two. Figure 3-1 summarises the steps and sequence of the different phases of the study.

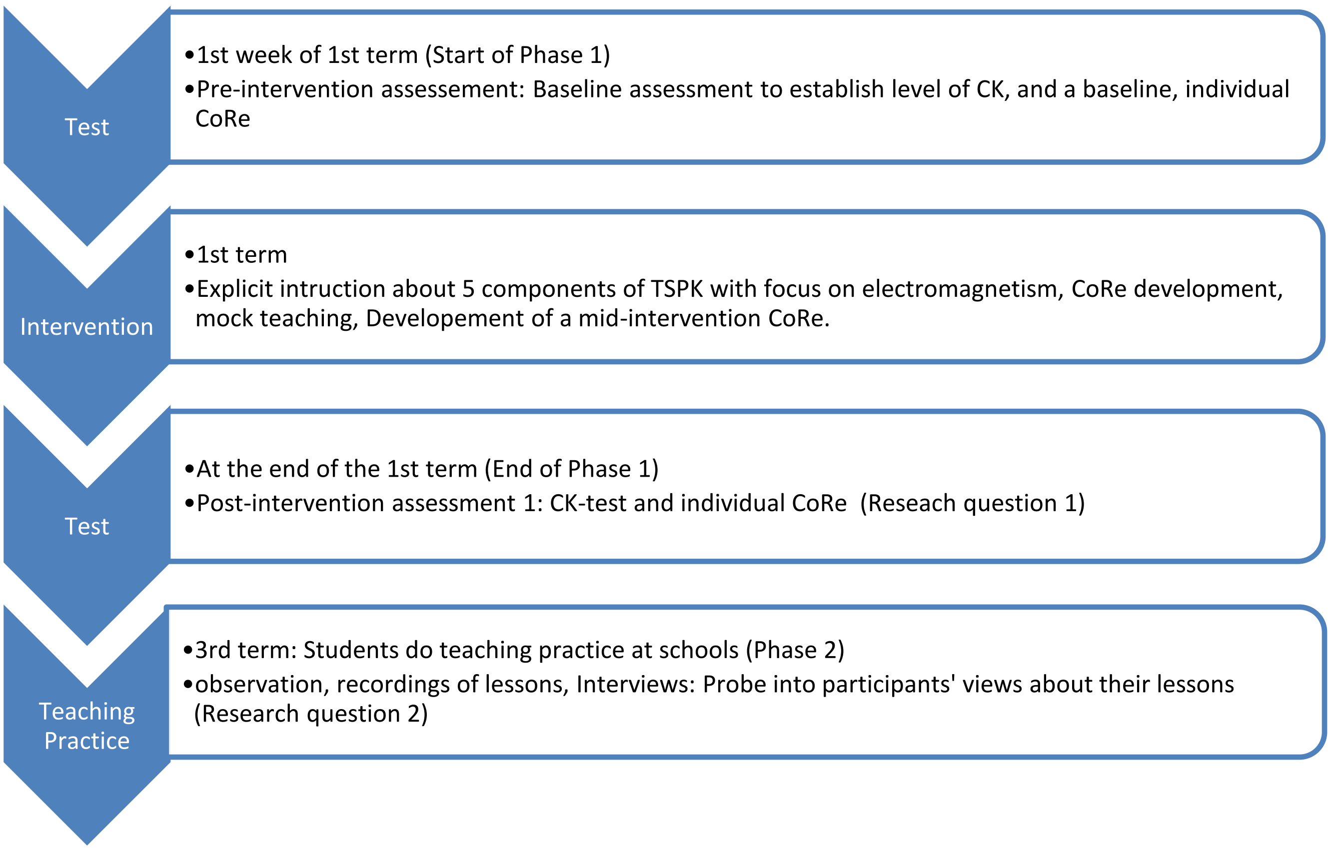


Figure 3-1: Diagrammatic representation of the research steps.

3.5 Instruments

3.5.1 The CK test

The purpose of the CK-test was to assess the level of CK of the pre-service teachers about electromagnetism, since the level of CK is closely linked to teachers' development of PCK about the content (Rollnick, 2017). The CK test (Appendix F) consisted of items selected from existing diagnostic tests (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001; Sağlam & Millar, 2006) and from items that I, developed for tests and examinations for pre-service Physical Science teachers over the period of ten years and that were adapted for the purpose of this instrument. The test was piloted with a group of pre-service teachers from another institution. Feedback from the students in terms of the wording of the items and clarity of diagrams was implemented to improve the test.

As explained in the research design (§3.4) the same test was administered before and after the intervention. The pre-test was written during the third session of the methodology course in which the intervention took place. The students were informed about the pre-test two weeks before the time through the electronic communicating system and verbally one week prior to the test. The post-test took place during the last session of the methodology course, after the conclusion of the intervention. Students were also informed that the results of both these tests would be incorporated in their final mark for their methodology module. There was a time restriction of 60 minutes on the CK tests, but all the students completed the tests before the time expired.

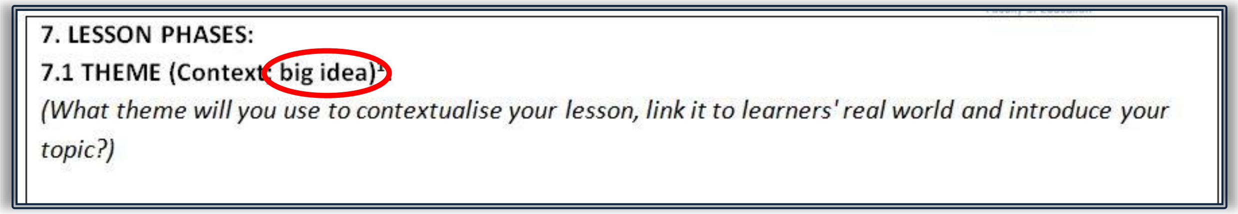
The outcomes of the CK tests were scored dichotomously and fed into RUMM2030 (Andrich, Sheridan, & Luo, 2011) for a Rasch analysis. Since only 14 participants wrote both CK-tests, the sample was too small for a full validation of the test, yet Rasch analysis showed that the test and the sample fitted the Rasch model and meaningful deductions could be made. These are discussed in detail in §5.2.

3.5.2 The CoRes

The CoRe tool (Loughran et al., 2004) was a valuable instrument in this study and was implemented to access, develop and assess the PCK of student teachers about electromagnetism. Nilsson and Loughran (2012) found that a group of pre-service elementary science teachers who were offered a science methods course using a CoRe methodology, indeed wrote richer and better developed CoRes after the intervention than before. Others (Mavhunga, 2012; Rollnick et al., 2008) have also used CoRes to track the development of teachers' PCK. Building on these, the intention during the present study was to expose pre-service teachers to CoRes as a tool to guide and assess their PCK in that it prompted them to reveal their pedagogical reasoning about teaching electromagnetism.

The CoRe tool used in this study was a version adapted by Rollnick and Mavhunga (2016), because, based on my experience in science teacher education, I believe it includes important questions on which a pre-service teacher should reflect when planning a lesson. This version of the CoRe tool has ten prompts which link with the five components of TSPCK in the framework of this study (Mavhunga, 2014; Mavhunga & Rollnick, 2011) as shown in Figure 2-2 (p.20).

For the purpose of this study the phrase "big idea" as used in studies by other researchers, was changed to "key ideas". The students participating in this study were obliged to plan their lessons according to a lesson plan template designed by the Faculty of Education where they studied. In this lesson plan, the term "big idea" was used to indicate an overarching theme in which the entire topic will be contextualised (see Figure 3-2).


7. LESSON PHASES:

7.1 THEME (Context: big idea)[1]

(What theme will you use to contextualise your lesson, link it to learners' real world and introduce your topic?)

Figure 3-2: Extract from the lesson plan template prescribed by the faculty of Education

From previous experience I realised that students found it difficult to distinguish between the term "big ideas" in the lesson plan and as it was intended in the CoRe tool; where it refers to main ideas into which the topic is broken down to help learners conceptualise the topic (Loughran et al., 2006; Loughran et al., 2004). That led to the term "big ideas" being replaced with "key ideas", preventing confusion between the term as used in their lesson plans and the way it was used in the CoRe tool.

In this study the students were required to construct an initial, individual CoRe (pre-CoRe) with the purpose of capturing their baseline personal PCK about teaching Gr 11 electromagnetism. Sixteen fourth year students completed the pre-CoRe. This, together with the CK pre-test counted a small percentage towards the students' grade for the module. The students had access to the Curriculum and Assessment Policy Statement (CAPS)(Department of Basic Education, 2011) for FET Physical Sciences while completing the CoRe, to ensure that they knew exactly what was required by the curriculum. They were instructed to choose three key ideas from Gr 11 electromagnetism and to write those in a sequence in which they thought they should be taught and then to complete the rest of the CoRe for each of the key ideas. The students received a paper-based template of a CoRe (see Figure 2-2) with space for three key ideas and were instructed to use the blank opposite sides of the pages if they needed more space for their responses. There were no time limitations and students could write until they were satisfied with the CoRe they had constructed.

The discussions during the intervention afforded the students the opportunity to learn about and deliberate on the components of TSPCK pertaining to Gr 10 magnetism, Gr 11 electromagnetism and Gr 12 electrodynamics. Although the focus of the study was on Gr 11 electromagnetism, the grade 10 and grade 12 topics were included in the intervention for students to develop an appreciation of the sequencing of concepts in the curriculum. The students were instructed to develop a CoRe for any topic in the above-mentioned sections of the curriculum and to present a mock lesson to their peers on this topic at the end of the intervention. These mid-intervention CoRes were used to familiarise the students with the TSPCK components and to teach them to use their CoRes in the planning of a lesson. These CoRes were not assessed for the purpose of the study.

The post-CoRe refers to a CoRe that was written at the end of the first term after completion of the intervention and, as for the pre-Core, only Gr 11 electromagnetism could be used as topic. This, together with the second CK assessment, was written as a final examination and took place under examiation conditions except that no time limitations were imposed on the students.

3.5.2.1 Scoring of the CoRes

The pre- and post-CoRes were scored using a rubric (Appendix G) to determine whether development in PCK of the pre-service teachers was evident. The rubric used by Zimmerman and Steinberg (2014) for scoring CoRes on electric circuits was adapted for electromagnetism. The rubric allowed for scoring the responses to each prompt on a four-point scale adapted from Park, Jang, Chen, and Jung (2011) with levels limited (1), basic (2), developing (3) and exemplary (4), where the numbers were used for quantitative analysis using the Rasch model. The scoring of the CoRes, the rigorous process of validating the rubric and the qualitative analysis of the CoRes using Atlas.ti are discussed in detail in Chapter 5 (§5.3).

An expert CoRe (Appendix H) against which the participants' CoRes were gauged was constructed and is referred to in the rubric as an example of exemplary PCK. This CoRe is informed by the content of the curriculum document on electromagnetism (Department of Basic Education, 2011), a CoRe on electromagnetic induction by Nkosi (2011), and the knowledge about and experience in teaching the topic of the researcher and two experienced Gr 11 science teachers.

The content related to electromagnetism which is required by the South African curriculum and on which the expert CoRe is based, can be summarised as follows:

- Gr 10: Magnetism; magnetic fields and field lines of permanent magnets, the earth's magnetic field and the compass.
- Gr 11: The magnetic field around a current-carrying conductor, magnetic flux, electromagnetic induction and Faraday's law.
- Gr 12: Electric motors, generators and alternating current.

I compiled the first draft of the expert CoRe while referring to the curriculum documents and Nkosi's CoRe on electromagnetic induction. This draft was given to two experienced science teachers and a science teacher educator who suggested changes and additions. It should be kept in mind that the expert CoRe was constructed for the South African FET science curriculum and is therefore not an exhaustive representation of knowledge about teaching electromagnetism.

3.5.3 Lesson observations and recordings

During the second stage of the study, three pre-service teachers were observed in their classrooms during their teaching practice. The purpose of the observations was to determine the extent to which the pre-service teachers transferred their PCK, as revealed in their written CoRes, into practice when they taught the topic. Since I, the researcher, also took on the role of mentor during their teaching practice, I had been a participant observer and had the benefit of discerning "on-going behaviour as it occurs and [was] able to make appropriate notes about its salient features" (Cohen et al., 2013, p. 298).

However, I was aware that my own biases and preferences about teaching electromagnetism might have clouded my observations and the analysis thereof and I was therefore open to consider more than one explanation for what I observed in the lesson presentations. Gall et al. (1996) suggest a way to counter the effect of biases during observations, namely to "[report] the research project in sufficient detail that readers can audit the findings" (p. 352). This was my endeavour in the thesis. The possible observer effects and biases that had to be taken into account are discussed in detail in §6.1.

Furthermore, I video-recorded at least 60 minutes of teaching by the pre-service teachers during their teaching practice. The advantages of recordings are that they can be replayed several times for reliable coding and one is able to capture behaviours and actions that cannot be anticipated when an observation schedule is used (Gall et al., 1996). Video recordings can also capture non-verbal data (Cohen et al., 2013), which may be useful when teachers use gestures and motions to explain certain ideas. To ensure that the recording of the video was not intrusive during the lesson, the person who was handling the camera tried to capture as much as possible of the participant without moving around in the classroom.

I searched the lesson presentation for evidence that students were employing and enacting knowledge attained during the intervention. I designed a rubric for lesson observations (Appendix L), assigning levels of *restricted*, *adequate* or *rich* (for each component) when judging the participants' enactment of their TSPCK, enabling me to give a credible report on the extent and quality of students' enacted TSPCK. Validity and trustworthiness of the rubric for enacted TSPCK were obtained by co-scoring the lessons with an experienced science teacher educator. The scores were discussed and category descriptions were refined until agreement was reached.

3.5.4 Interviews

A video stimulated recall (VSR) interview followed by a semi-structured interview was conducted with each of the participants after the last lesson observation. VSR interviewing is a technique where a video recording of a teacher made during a teaching activity, is played back to the teacher while eliciting her thoughts about the events seen in the video (Nguyen, McFadden, Tangen, & Beutel, 2013). It should be noted that the focus is not on recalling the event or the exact thinking and reasoning when the event occurred but to stimulate the teacher's reasoning and reflection about her teaching when reminded of the event (Denley & Bishop, 2010). The teacher can reflect about what she was doing and why and whether she could have done it differently. Since pedagogical reasoning reveals a teacher's sensitivity and decision making in response to the context, it cannot be accessed through observation data only (Chan et al., in press).

The semi-structured interviews (interview schedule in Appendix M) that followed the VSR interviews enabled me to probe deeply into the participants' views about their experiences in general while teaching the topic of electromagnetism.

3.6 Data analysis strategies

The performance of the pre-service teachers in the pre-and post-intervention CK tests and CoRes were analysed and compared. The difference in performance was considered to establish whether explicit instruction in the components of TSPCK contributed significantly to an improvement in CK and PCK about electromagnetism. The lesson recordings and interviews were analysed to establish the extent to which students were able to enact their TSPCK in teaching activities. Analysis of the data took place in five stages:

- Quantitative analysis of the pre- and post-CK test results (Rasch analysis) (§5.2.4)
- Interpretive, qualitative item analysis of the pre-and post-CK test results (§5.2.5)
- Quantitative analysis of the CoRe responses (Rasch analysis) (§5.3.3)
- Interpretive, qualitative analysis of the CoRe-responses (§5.3.4)
- Qualitative analysis of the lesson recordings and interviews (Atlas.ti) (§6.2)

Although Rasch statistical analysis is not usually done with small samples, it has been implemented in earlier studies about the development of PCK (Mavhunga & Rollnick, 2011, 2013), where it was used to establish the validity of instruments. According to Boone, Staver, and Yale (2014), the question about sample size is a circular one, where the sample size depends on the item distribution along the linear scale and the distribution of items is determined by the distribution of the respondents along the trait under investigation. Care has to be taken to ensure that persons are evenly distributed along the trait and that items do not overlap. How this was considered in the current study is discussed in detail in Chapter 5. In this study Rasch analysis was a useful tool in establishing the functioning of the CK test instruments (Boone & Rogan, 2005), the CoRe tool and the rubric and when making inferences about item difficulty and person ability. Rasch analysis places the items in a test on a linear scale of item difficulty and the participants in the sample (referred to as *persons* in Rasch analysis) on the same linear scale in terms of person ability related to the test (Wright & Mok, 2004). I used the Rasch Unidimensional Measurement Models (RUMM2030) software for the Rasch analysis in this study and the techniques of racking and stacking to analyse the pre- and post-intervention data.

A specific way of looking at data collected before and after a sample was subjected to an intervention, is that the participants change as a result of the intervention, whereas the "change" in this study refers to the acquisition of CK and knowledge about components of TSPCK. Comparison of the participants' ability before and after the intervention can be done by stacking the Rasch data (Cunningham & Bradley, 2010; Wright, 2003). This technique is possible when the pre- and post-instruments are identical as was the case in this study. For this analysis, the test results were fed into the software as for a single test written by two groups, which effectively doubles the number of persons and thus increasing the sample size. Stacking the data for this study resulted in an effective sample size of 28. Rasch analysis was done with the stacked data and it was established that the data fit the Rasch model for both the CK test and the CoRe (described in Chapter 5). The RUMM2030 software allows for assigning a person factor (pre- and post-) to the pre- and post-attempts of the participants and enabled me to make inferences about the development of the participants' CK and TSPCK.

In a research field such as physical sciences, it is important that the instrument of measurement does not change. However, in a study such as this, one expects the instrument to change as perceived by the participants, in the sense that although the test stays the same, the students find the items easier after the intervention. Racking the data enables the researcher to determine the change in item-difficulty from the pre-test to the post-test as perceived by the participants (Wright, 2003) and inferences can be made about what knowledge was attained and what was not attained. Data is racked when the pre-and post-tests are analysed simultaneously as two different tests placed on the same linear scale, which makes it possible to compare the responses to post-test items and pre-test items directly. In this study, racking the data effectively increased the number of items to 48. In the analysis, I have distinguished between items from the pre- and post-tests by labelling them differently. A detailed report about the Rasch analysis in this study is given in §5.2 and §5.3.

The videos and the interviews were analysed in Atlas.ti using pre-determined codes, which were the five components of TSPCK of the framework of the study. The lesson videos were not transcribed since the Atlas.ti version I used allowed for coding video material directly. Frames in the videos representing events in the lessons portraying enactment of specific TSPCK components, were selected and coded. Remarks during the VSR interview where students referred to these events and revealed their related pedagogical reasoning were similarly coded. A detailed description of the coding process, the analysis and interpretation of the lesson recordings is given in Chapter 6.

3.7 Credibility and trustworthiness

Research is worthless if the findings from the research are not valid, credible or trustworthy. Leedy and Ormrod (2005) define these terms as "the extent to which others perceive the study's findings to be convincing and worth taking seriously (p. 262)". Triangulation is an important method to obtain credibility in qualitative research (Creswell, 2012). Triangulation involves different methods of data collection in the hope that information will be obtained that converges towards a well-defined theme. In this study triangulation is achieved by capturing participant's PCK about electromagnetism by completing personal CoRes at two stages during the study, by observing the participants in actual teaching situations and then interviewing them about the decisions they made during their teaching.

The fact that I am involved in the participants' training and have assessed their assignments to obtain a final grade for the methodology module, may be a threat to the validity of the study. The halo effect might have played a role and I therefore reminded myself to interpret the CoRes of each participant and the observations of their teaching at "face value" and not to be influenced by the opinion I had previously formed about the quality of their work. Rigorous adherence to the category descriptions of the CoRe-rubric and the enacted TSPCK-rubric served to address and reduce these observer effects.

Member checking or member validation can also ensure credibility. This involves taking back the results and the researcher's interpretation thereof to the participants, asking them to judge whether these accurately reflect their perceptions and interpretation of the social construct being studied (Neuman, 2007). Member validation would not serve a purpose because of the nature of this study. Since I was the mentor lecturer for the participating students, I was obliged to have mentoring discussions with the participants after I had observed their teaching. These mentoring discussions were held after the interviews had been conducted. As a result, their opinion of what entails good teaching might have changed, and they might have decided to retract or change comments made in their interviews. I considered the interviews a revelation of what they had learned from the intervention and experience and as their untainted pedagogical reasoning and perception of their own teaching. I engaged other researchers and experts in the field to interpret the data independently and then compared and discussed the interpretations. Different experts illuminated different dimensions in the data and the subsequent interpretations were richer and more exhaustive (Neuman, 2007).

The next section provides a summary of the research design in tabular form, followed by a discussion of the ethical considerations related to this study.

3.8 Summary of the research design

<table>
<tr><td>Research strategy</td><td colspan="2">Case Study</td></tr>
<tr><td>Participants</td><td colspan="2">Fourth year pre-service students enrolled for a Bachelor's degree in Physical Sciences education.
This group of students go to schools for teaching practice in the second and third terms of their fourth year.
In the first term they attend methodology classes in all their electives: Physics methodology and Chemistry methodology in the case of the participants in the study.</td></tr>
<tr><td>Main question</td><td colspan="2">How is the development of the PCK of pre-service teachers influenced by the explicit inclusion of TSPCK about electromagnetism in pre-service teacher education?</td></tr>
<tr><td>Research sub-questions</td><td>1. What is the impact of an intervention, focussing on the components of TSPCK, on the level of CK and PCK of pre-service teachers in electromagnetism?</td><td>2. To what extent is PCK learned during the intervention manifested in the practice of pre-service teachers as revealed during Teaching Practice?</td></tr>
<tr><td>Objective of the sub-questions</td><td>To establish whether the instruction and guidance (designed by the researcher) that pre-service teachers receive during course work in the methodology class have an impact on the CK and PCK of the pre-service teachers.</td><td>To establish whether the PCK that the pre-service teacher developed during the methodology course is put into practice when they teach.</td></tr>
<tr><td>Data collection instruments</td><td>Baseline assessment and post-assessment (pre- and post-CK tests)
First individual (pre-) CoRe and second individual (post-) CoRe.</td><td>Observations and video recordings
Semi-structured and VSR interviews</td></tr>
<tr><td>Data analysis</td><td>CK tests were scored and compared using Rasch analysis.
The CoRes were scored using a rubric and compared using Rasch analysis to establish whether the methodology course had an impact on the TSPCK of the pre-service students.
Interpretive, qualitative analysis of the responses to the CK-items and CoRe prompts were done to establish the nature of the impact on the CK and PCK of the students.</td><td>The lesson presentations and interview responses were scrutinised for evidence of the enactment of the TSPCK components.</td></tr>
</table>

3.9 Ethical considerations

The level of sensitivity of the study was low, since it was unlikely that any information of a personal nature about the participants would become known during the study. However I still ensured that the identity of the students and the responses and information given by them were treated confidentially. I conducted the study complying with all the ethical requirements and received ethical clearance from the Ethics Department at the university where I conducted the study. The following institutions and individuals were asked for permission to conduct the research: the Gauteng Department of Education, the dean of the Faculty of Education where the participants were registered students, the head of the Teaching Practice office arranging the school visits of the students and the principals and school governing bodies of the schools where the participants did their teaching practice.

Given that the participants in the study were fourth year students enrolled for the methodology module in the BEd (FET) Natural Science program, they constituted a captive audience. I informed them in writing that participation was voluntary and that non-participation or withdrawal would not influence their grades for the course. I obtained informed consent from these students to participate in the study. Since the students conducted their lessons from which I collected data in the class of their mentor teachers, I also obtained informed consent from the mentor teachers, the parents of learners as well as assent from the learners who were present in the classes where the participants were observed and video recorded. In all the schools only one learner's parents did not give consent and this learner was placed behind the camera in the class so that there would be no chance of this learner being captured on the video camera. At all times care was taken not to capture the faces of learners on the video camera.

All the role players mentioned above were presented with a letter of informed consent that contained the following information (Leedy & Ormrod, 2005) (see Appendix N):

- A statement that participation was strictly voluntary and could be terminated without fear of discrimination against them should they choose to withdraw;
- A description of the study, explaining the gaols and what participation would involve; and

- A guarantee that all responses and information obtained would be treated confidentially and anonymously. The parents of the learners were ensured that the anonymity of their children would be protected during the video-recording of the lessons.

The pre-service teachers benefitted from the study in the sense that they were given an opportunity to develop their knowledge about teaching a topic that is normally considered difficult.

Chapter 4

The intervention:
Teaching PCK of electromagnetism

The overarching purpose of this study is to establish whether the teaching and mentoring pre-service teachers receive during their fourth year in the subject methodology class and teaching experience at schools, indeed contribute to the development of their PCK. An intervention with explicit focus on the TSPCK components described in the framework was designed to be incorporated in the physics methodology module. In this chapter the structure of the teacher education programme in which the participants were enrolled is outlined so that the place of the intervention in this programme can be understood. This chapter further presents a description of the intervention and how it unfolded during the methodology class.

4.1 Introduction

As explained in Chapter 3, the participants in the study were fourth-year BEd students. The BEd programme consists of compulsory, generic modules related specifically to education and teaching and elective modules, which include the subjects in which the students specialise. A very important component in the generic category is the education modules where students are exposed to general issues in education and teaching: These modules comprise topics such as the historical and cultural complexities of teaching, child development and learning and the curriculum in the classroom. The elective modules (also called specialisations) of the participants in the study included physics, chemistry and mathematics. These elective modules are not taught in the Education Faculty but in the "mother" faculty and departments of these subjects at the same university. The elective modules include two methodologies of teaching; one for physical sciences and the other for mathematics. These modules are taught during the third and fourth (final) year of study in the Faculty of Education. During the final year of study, the students visit schools for a total of 20 weeks for their teaching practice modules (see concept clarification in §1.1.1).

The intervention took place as part of the module called "Methodology of Physical Sciences" in the fourth year of the BEd programme. This module will be referred to as MPS in the paragraphs to follow. The module is divided into chemistry and physics components, which are taught separately by two different lecturers, while focussing on common outcomes as stipulated in the module study guide (See Appendix B). The purpose of the methodology module is the development of the following competencies:

- to interpret the core curriculum pertaining to physical sciences
- to plan and design lessons and present them successfully
- to plan and administer assessment procedures
- to acquire teaching knowledge and skills.

The purpose of this module made it suitable for incorporating the intervention for this study.

4.2 The intervention

The participants in the intervention were all students enrolled for the methodology course in their fourth year in 2016. (See a profile of the participants in §3.3) In this study the pre-service teachers enrolled for the MPS module will be referred to as "the students". "The curriculum" in this section refers to the topics magnetism, electromagnetism and electrodynamics in the Gr 10-12 South African school curriculum (CAPS 2011) (see Appendix A).

During the intervention the five components of TSPCK as stipulated in the framework for the study (see §2.4) were explicitly addressed using appropriate sub-topics in magnetism and electromagnetism and the way every one of the five components supports the transformation of CK for teaching was communicated. Below follows a summary and then a description of how the intervention was included in the MPS module. Themes 5 and 6 were selected to pilot with a group of pre-service teachers from another university, because this institution only had two sessions available for this purpose. The feedback from these students was used to refine the intervention.

Before the intervention commenced the students were notified about the upcoming CK test (see §5.2). The scope of the test was the content described in the curriculum for magnetism Gr 10, electromagnetism Gr 11 and electrodynamics Gr 12 and the pre-concepts related to these topics. Since the pre- intervention assessment included writing a personal CoRe on electromagnetism (called the pre-CoRe), the structure of the CoRe was also discussed. It should be mentioned that the students had been exposed to CoRes and had the opportunity to write a personal CoRe on Gr 10 electricity during their third-year methodology course.

Students were also informed, at the beginning of the intervention, of the micro-lesson they would be presenting in class on a topic from Gr10 magnetism, Gr 11 electromagnetism or Gr 12 electrodynamics. For this they had to construct a CoRe that had to be submitted together with their lesson plan as an assignment. These CoRes are referred to as mid-intervention CoRes and are used as evidence of students' development during the intervention in the discussion that follows. The micro-lesson presentations were not used as data, but served as an exercise for the students to put their newly attained TSPCK into practice. Lesson observations during actual teaching are an element of the next part of the study and will be discussed in Chapter 6.

During this discussion of the intervention, I draw extensively from the reflective journal (Appendix D) that I kept during the six weeks of the intervention. I wrote comments in this journal every day after teaching a particular theme indicated in the summary. I reflected on discussions that took place between me and the students and on my perceptions of student responses. To support my narrative, I include photographs taken of certain artefacts and drawings used during the intervention. Table 4-1 shows the summary of the intervention of which a full structure is given in appendix C. Appendix B is the study guide, which indicates how the intervention was incorporated in the methodology module.

Although one of the TSPCK components was the focus of each theme, as shown in Table 4-1, none of the components could be discussed in isolation. The last column of Table 4- 1 shows how the themes linked with the conceptual framework, which led to a constant reminder of the interaction of the components.

Table 4-1: Summary of the intervention

Session (2 hours)		**Activities**	**Assessments** Those marked with * will be part of the data collected to answer the research questions	**Link to research framework**
Session 1		• Administrative aspects • Introductory discussion on PCK, TSPCK and the components of TSPCK • Discussion of the CoRe template		
Session 2	Theme 1	PCK, TSPCK and the components of TSPCK (continued) • Reading : Shulman (1986), Shulman 2015, Mavhunga, & Rollnick (2013), Loughran et al. (2004) (short test) • Discussion of CoRe template	PCK test on articles (30 min)	TSPCK CoRes and TSPCK components
Session 3		Administration of CK test Complete first personal CoRe on Gr 11 electromagnetism – 3 key ideas Gr 11 (no time restriction)	*CK test and initial personal CoRe on electromagnetism (Pre-CoRe)	
Session 4	Theme 2	Curricular saliency • Unpack magnetism and electromagnetism from CAPS • Discuss the sequencing of key ideas • Pay particular attention to the fact that knowledge about the Lorentz force is not explicitly required, although it is needed in Gr 12 where the concept of electric motors is prescribed.		Curricular saliency

Session 5	Theme 3	Conceptual teaching strategies
		• Discussion of teaching strategies as required in lesson planning
		• Discussion of components of an effective strategy
		  ○ Understand learners' thinking
		  ○ Use appropriate representations and/or analogies
		• Employing particular strategies for conceptual teaching of key ideas
				Conceptual teaching strategies
				Representations
				Learner prior knowledge

Session (2 hours)		**Activities**	**Assessments** Those marked with * will be part of the data collected to answer the research questions	**Link to research framework**
Session 6	Theme 4	Learner prior knowledge and misconceptions • Prior reading Saglam and Millar (2006) • Magnetism Gr 10 - Knowledge that should be in place before teaching electromagnetism in Gr. 11 • Discuss teaching strategies, approaches and representations to address the misconceptions and alternative thinking. ○ Learners do not distinguish between electric charges and magnetic poles ○ Learners are not aware that magnetic fields are 3D ○ Learners are not aware that compass needles are tiny magnets	Assignment: Magnetism Gr 10 - misconceptions	Prior knowledge Curricular saliency Teaching strategies Representations
Session 7	Theme 5	Representations: Focus on • Practical demonstrations, use of apparatus • How to use computer simulations • Using the right hand to represent the relationship between the directions of vector quantities in electromagnetism. • Drawing magnetic fields - How to represent 3D magnetic fields on a 2D writing surface		Teaching strategies Representations
Session 8	Theme 6	Identifying key ideas in electromagnetism (gr 11) • What are the key and subordinate ideas when dealing with electromagnetism in Gr11? • What topics or sub-topics are difficult to teach? Why? • How do topics in Gr 10 and Gr 12 link with the Gr 11 topics?		Curricular saliency Learner prior knowledge What is difficult to teach?

Session (2 hours)		**Activities**	**Assessments** Those marked with * will be part of the data collected to answer the research questions	**Link to research framework**
Session 9	Theme 7	Identifying key ideas in electromagnetism (Gr12) • What knowledge should be in place when teaching generators and motors? • What is difficult to teach when dealing with generators and motors? Why? • Using simulations available on the internet when teaching these concepts.		Curricular saliency Representations What is difficult to teach?
Session 10	Theme 8	Putting your TSPCK into practice Drawing the five components of TSPCK together Lesson design and presentations. Finalise mid-intervention CoRe for lesson	Assignment: (i) Lesson CoRe (ii) Design lesson (iii) Lesson presentation	Transferring TSPCK to practice
Session 11		Lesson presentation and peer assessment.		
Session 12	End of intervention	Lesson presentation and peer assessment.		
Session 13	Theme 9	Assessment (not part of intervention)	Assignment: Design a test	
Session 14		CK test Complete a second personal CoRe on Gr 11 electromagnetism	*Second CK test *Second CoRe (Post-CoRe)	

4.2.1 Theme 1: Teacher knowledge: PCK, TSPCK and its components

Since PCK is a hidden construct (Kind, 2009), implying that teachers are often not aware that is it something they possess, the existence of the construct is not generally known to teachers or pre-service teachers. In the normal course of events students attending the methodology module have had little or no formal experience of teaching; it is therefore also a fair assumption that they would not realise the significance of the PCK construct. Theme 1 of the intervention served as an introduction to PCK and related issues. Students were exposed to early literature about PCK and some recent developments, with the focus on the topic-specific nature of PCK, the components of TSPCK proposed by Mavhunga (2012) and CoRes as a method of capturing the PCK of an individual.

During class discussions it became evident that the articles the students were instructed to read were indeed their first introduction to the PCK construct. To ensure that students read these articles, they wrote what was called a PCK test on the content of the reading matter. PCK was a novel idea to them, but one to which they related very well. Although they did not have formal exposure to teaching, some of them had been involved in private tutoring of FET learners in mathematics and science and from their experience they agreed that PCK is indeed topic specific, because they realised that they were more comfortable teaching certain topics than others. However, they could not pinpoint the reasons for being able to teach certain topics with more confidence, other than better CK and deeper understanding. As a result, the discussion about the five components of TSPCK revealed to them the teacher knowledge they tacitly had or that they ought to have when attempting to teach a specific topic. At the end of the discussion, they concurred that, if they had knowledge about those five components about any given topic, they would have increased confidence to teach it.

Towards the end of the discussion, however, it was clear that the students had not yet internalised the idea of PCK and had not integrated the construct in a framework in terms of which they thougt about teaching. The discussion was consolidated by the following question: Suppose you were a senior teacher and the principal asked you to assess the level of the PCK of a novice teacher on a certain topic, what would you be looking for? The response was somewhat unexpected; as I remarked at the time:

I expected that the students would refer to the five components of topic specific PCK. It was surprising that students focussed primarily on the other knowledge bases of teachers and in a sense ignored topic specific PCK. Their answers included:

- *The teacher must be able to maintain discipline.*
- *The teacher should not make mistakes on the board.*
- *The teacher should be able to use an overhead projector or data projector if available.*
- *The teacher should speak clearly and talk to all the learners in the class.*
- *The teacher must be well prepared.*

It was evident that, although the students had an intuitive sense of the requirements for the effective teaching of a topic, they did not think about themselves and their own practice or the practice of their peers in those terms yet.

4.2.2 Theme 2: Curricular saliency: Electromagnetism in the Gr 10-12 South African curriculum

Electromagnetism is considered a challenging section for both teachers and learners in the physics school curriculum of many countries (Maloney et al., 2001; Sağlam & Millar, 2006; Smaill & Rowe, 2012) and it seems to be the case for the group of participants in the study as well. The fourth-year students in the MPS class had passed at least one complete year of university physics where magnetism, electromagnetism and electrodynamics were part of the content covered; only three of the participants had completed a third-year course in physics. Because the students' exposure to these topics was three years in the past at the time of the intervention, it was thought that a thorough analysis of the curriculum document would help them recall the content and link it to their own prior knowledge.

The idea was to focus on the sequencing of the topics in the school curriculum without extensive discussion of each topic. As it turned out, the CK of the students about this section of the work was very poor and they only had a vague memory of dealing with these topics at school or even during their first year of undergraduate physics. When I drew a diagram of a coil with its magnetic field on the board, the students seemed to be able to recall seeing such a diagram in the past. At this stage, I decided to present the PowerPoint slideshow (Appendix E) intended for theme 5 that focussed on the diagrams used in electromagnetism teaching. The content of this slideshow served to remind the students briefly of some of the important concepts while the curriculum was discussed. Figure 4-1 shows a typical slide in the slideshow.

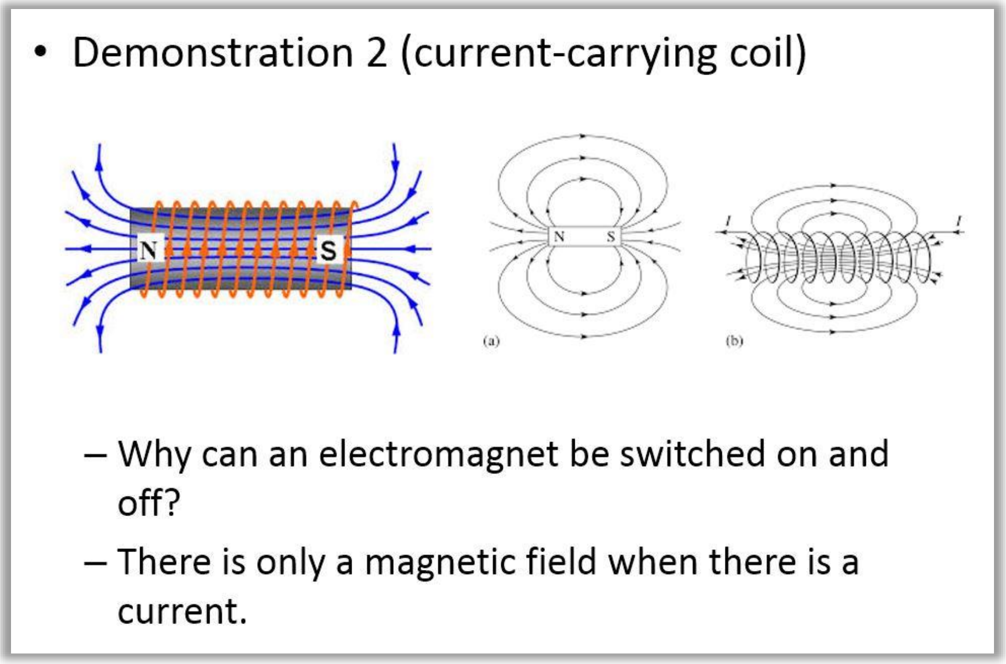


Figure 4-1: An example of the slides in a PowerPoint presentation focussing on diagrams to be used in electromagnetism teaching

Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
<u>Electrodynamics</u>				
Electrical machines (generators, motors)	• State that generators convert mechanical energy to electrical energy and motors convert electrical energy to mechanical energy • Use Faraday's Law to explain why a current is induced in a coil that is rotated in a magnetic field. • Use words and pictures to explain the basic principle of an AC generator (alternator) in which a coil is mechanically rotated in a magnetic field • Use words and pictures to explain how a DC generator works and how it differs from an AC generator • Explain why a current-carrying coil placed in a magnetic field (but not parallel to the field) will turn by referring to the force exerted on moving charges by a magnetic field and the torque on the coil • Use words and pictures to explain the basic principle of an electric motor	**Project:** Build a simple electric generator **Project:** Build a simple electric motor	**Materials:** Enamel coated copper wire, 4 large ceramic block magnets, cardboard (packaging), large nail, 1.5 V 25mA light bulb. **Materials:** 2 pieces of thin aluminium strips 3cmx6cm, 1.5 m of enamel coated copper wire, 2 lengths of copper wire, a ring magnet (from an old speaker) a 6cmx15cm block of wood, sandpaper and thumb tacks.	The basic principles of operation for a motor and a generator are the same, except that a motor converts electrical energy into mechanical energy and a generator converts mechanical energy into electrical energy. Both motors and generators can be explained in terms of a coil that rotates in a magnetic field. In a generator the coil is attached to an external circuit and mechanically turned, resulting in a changing flux that induces an emf. In an AC generator the two ends of the coil are attached to a slip ring that makes contact with brushes as it turns. The direction of the current changes with every half turn of the coil. A DC generator is constructed the same way as an AC generator except that the slip ring is split into two pieces, called a commutator, so the current in the external circuit does not change direction. In a motor, a current-carrying coil in a magnetic field experiences a force on both sides of the coil, creating a torque, which makes it turn.

Figure 4-2: Excerpt from Gr 12 physical sciences curriculum

An important aspect that I expected the students to realise while discussing the order of concepts in the curriculum, was the inadequate reference to the force experienced by a current-carrying conductor, as is evident in the excerpt from the curriculum document in Figure 4-2. This concept is not explicitly discussed in earlier grades and in the Gr 12 section it is merely mentioned in the teachers' guidelines. The students were unable to identify this obvious gap in the curriculum and I had to alert them to the possible consequences of its omission.

Furthermore, magnetic flux is introduced under the heading of Faraday's law and not explicitly as a sub-topic on its own. This aspect was discussed and students agreed that an explicit discussion about magnetic flux would be beneficial if it is done before introducing Faraday's law. The sequence that students accepted was to show electromagnetic induction as a phenomenon, without referring to Faraday's law, but to explain magnetic flux through a loop first.

4.2.3 Theme 3: Conceptual teaching strategies

The prescribed lesson planning form that students have to complete during their teaching practice includes a section on teaching strategies as shown in the selection from the lesson planning form in Figure 4-3. Knowledge about general teaching strategies can be regarded as prior knowledge of the students, since they completed a section about this during their second year in one of the education modules. Although *Conceptual teaching strategies* is the component that entails the integration of the other components, the decision was made to discuss this component first, in order to address students' predetermined idea about teaching strategies and indicate how it relates to *Conceptual*

5.3. TEACHING STRATEGIES AND TECHNIQUES *(I used... to meet the lesson outcomes)*

❑ Direct Instruction: ❑ Socratic question and answer	❑ Guided discovery: ❑ Inquiry-based learning ❑ Cooperative learning ❑ Pair work ❑ Small group work ❑ Role-play	❑ Solving real life challenges (no guidance)	❑ Combination: *(Specify)* ________ ________ ________ ________	❑ Other: *(Specify)* ________ ________ ________ ________

Justify your choice(s):

____
____
____

Figure 4-3: Extract from lesson planning form *teaching strategies*. In this session some of the teaching strategies mentioned in the lesson planning form were recalled, namely discussion (question and answer), inquiry-based learning, small group work, problem-solving and direct instruction. The students were expected to consider each of the teaching strategies and its incorporation in a conceptual teaching strategy in the Physical Sciences classroom when teaching electromagnetism. During the discussion, students identified the following components of a successful teaching strategy, again focussing on aspects of general pedagogy: plan the lesson properly, plan to involve learners, speak clearly and make eye contact. When encouraged to think about exactly what should be included in the planning of the lesson, students were able to acknowledge the importance of planning demonstrations and experiments. Eventually they also realised the importance of paying attention to concepts that learners usually struggle to understand while learning a certain topic. When guided, students were able to recognise aspects of teacher knowledge related to the TSPCK components, such as the use of representations and knowledge of learners' thinking, in an effective conceptual teaching strategy and eventually agreed that the components should be integrated. The interaction of the components in a conceptual teaching strategy was considered the primary focus of this session.

My impression was that the students felt most comfortable with procedural teaching as a strategy and that they had not yet develop the skill of formulating questions that require conceptual thinking. When constructing a CoRe for the micro-lesson, the students persisted in suggesting strategies in line with the lesson planning form. See for example the extracts (Figure 4-4) from the mid-intervention CoRes of two students' responses to prompts D1 and D2 for one key idea.

D. Conceptual Teaching Strategies	
D1. What teaching strategies would you use to teach this key idea? D2. What questions would you consider important to ask in your teaching strategy?	~~Constructivism and~~ direct instruction (Socratic question and answer) as well as inquiry based learning. → ?

D. Conceptual Teaching Strategies	
D1. What teaching strategies would you use to teach this key idea? D2. What questions would you consider important to ask in your teaching strategy?	D1. Direct instruction

Figure 4-4: Students BM's (top) and TM's responses to prompts D1 and D2

Note student BM's reference to "Socratic question and answer" and "inquiry-based leaning", which appear as options in the lesson planning form (Figure 4-3). It was evident from these examples that the students had not developed the ability either to report on or design conceptual teaching strategies at that stage.

4.2.4 Theme 4: Learner prior knowledge and misconceptions: Magnetism Gr 10

In this section attention was paid to learner prior knowledge in the context of magnetism Gr 10 in the FET curriculum, so that students would have a sound idea of the knowledge that ought to be in place before teaching electromagnetism in Gr 11. Typical misconceptions and ways to address these misconceptions were discussed. When asked about typical learner thinking about magnets that the students knew about, the following transpired:

- One student mentioned that learners think that magnets attract all metals. This led to a discussion among the students, since some of them had the same idea and did not agree with their peers that this was a misconception. When asked which metals are attracted by magnets, some named copper and aluminium. I suggested that they test their ideas with actual magnets that I handed out; they soon agreed that not all metals are attracted to magnets, but they could at that stage not mention any other than steel that are attracted.
- Students mentioned that learners think that if one cuts a magnet in half, one will separate the north and south poles. This is a well-known misconception learners have and is addressed in the curriculum. Student HD mentioned this in her response to prompt A1, see Figure 4-5:

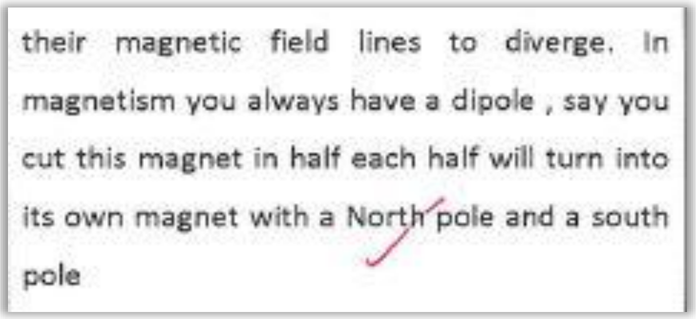

their magnetic field lines to diverge. In magnetism you always have a dipole , say you cut this magnet in half each half will turn into its own magnet with a North pole and a south pole

Figure 4-5: Part of students HD's response to prompt A1

- The students suggested that learners think that nothing will happen to a magnet if one drops it. When prompted about why one should not drop a magnet, the students were unable to give a reason.

- They mentioned that learners probably do not know that a compass needle is a magnet itself. (Three students revealed during the pre-CK test that they had this misconception themselves.)
- The students also mentioned that learners do not distinguish between north and south poles and negative and positive charges and will easily talk about the positive pole of a magnet. This misconception is well documented (Maloney, 1985). Students referred to this misconception in prompt C1 in their mid-intervention CoRes (see Figure 4.6). Student HD's response to prompt A3 in her pre-CoRe (written before the intervention) also indicated this misconception (Figure 4-7). Her pre-CoRe was written in her first language, Afrikaans, and the translation of her response is given next to her response.

C. Learner prior knowledge	
C1. What are typical learners' misconceptions when teaching this idea?	A north pole is positively charged and a south pole negatively charged. Field lines are in a 2D plane.

C1. What are typical learners' misconceptions when teaching this idea?	Magnetic poles are electric charges Magnetic poles can be isolated like electric charges

Figure 4-6: Students NL's (top) and KM's (bottom) responses to prompt C1

te uit te werk, Hulle moet weet hoe lyk magneet veld lyne en wat is die aard van die lyne as jy n positief/ Negatiewe magnete het (N/S)	...................................They must know what magnetic field lines look like and what the nature of the field lines are if you have positive and negative magnets (N/S)

Figure 4-7: Student HD's response to A3 (Pre-Core)

During the class discussion specific aspects to consider when practically showing the magnetic field lines around magnets with iron filings and compasses, were addressed. Drawing magnetic field lines on the board and other useful diagrams were discussed.

4.2.5 Theme 5: Representations: Teaching electromagnetism Gr 11

This session was devoted to practical demonstrations and diagrams that could be used to support the teaching of key ideas in electromagnetism. The PowerPoint presentation used in theme 2 was used again alongside the discussion of the demonstrations. The following demonstrations were reviewed:

- the existence of a magnetic field around a long straight current-carrying conductor;
- the magnetic field around a current-carrying coil;
- a moving charge experiences a force in a magnetic field;
- a current-carrying coil in a magnetic field experiences a force. The key idea (force on a current-carrying conductor in a magnetic field) addressed in this and the previous demonstration, does not appear in the curriculum, but is required as existing knowledge in electrodynamics Gr 12. Students were alerted to this possible gap in the knowledge of learners; and
- inducing a current in a coil when magnets move in and out of the coil.

In the first demonstration showing the magnetic field around a straight current-carrying conductor the apparatus shown in Figure 4.8 was used, first with iron filings and then with compasses, showing the existence of a magnetic field.

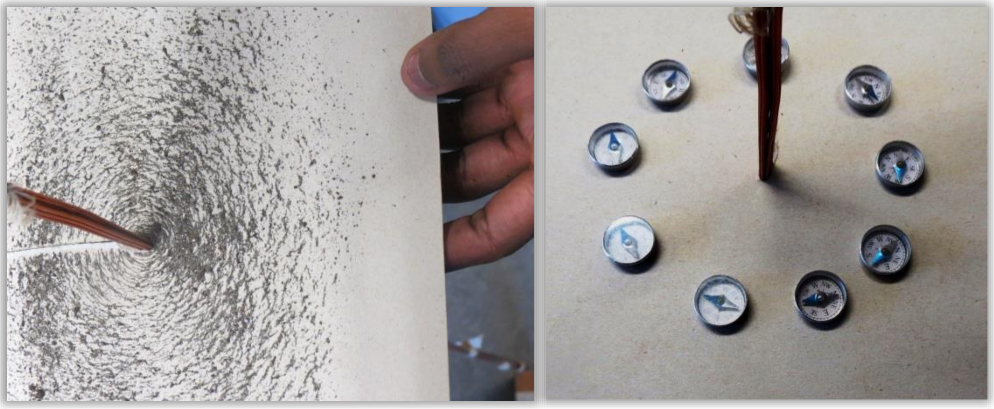


Figure 4-8: Magnetic field around a straight current-carrying conductor

Students were challenged to think about sequencing when teaching this topic. They were asked whether they would first teach the theory and then show the demonstration or first demonstrate the actual phenomenon and then ask learners what they thought the explanation was. The students agreed that the second approach was a constructivist approach[1] and was their preferred strategy. They also thought that the right-hand rule

[1] In the lesson planning form prescribed by the faculty, constructivism is suggested as an option that students can select as a teaching approach .

(RHR) for determining the direction of either the magnetic field or the current should be introduced using the apparatus. They found the discussion of the “dart analogy” to remember what the dot [⊙] and cross [⊗] represent very useful, where learners are told to visualise the back of a receding dart, seeing the crossed feathers, and of an approaching dart seeing the tip of the dart as a dot.

In the third demonstration a cathode ray tube was used to show the effect of a magnetic field on a beam of moving electrons (Figure 4.9). The students conceded that it is important for learners to first understand that the beam is a beam of electrons and then to show the effect of the magnetic field on the beam. The RHR to determine the direction of the force had also been explained here.

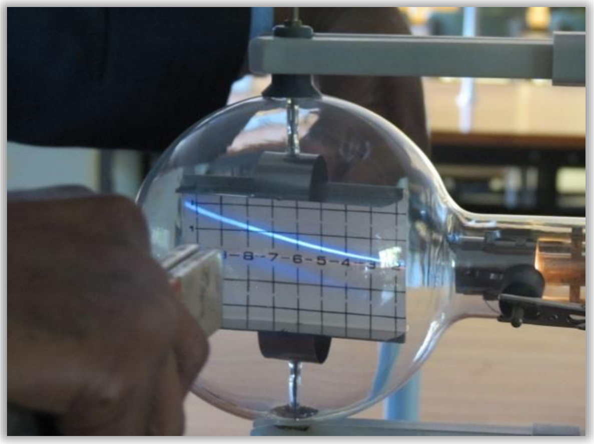


Figure 4-9: Cathode ray tube showing deflection of an electron beam in a magnetic field.

The students were enthusiastic and responsive during these demonstrations and ensuing discussions. Many of them commented that it was the first time they could remember seeing demonstrations like these. During discussions students were alerted to the type and timing of questions that may be asked to support the transformation of content for conceptual understanding.

Diagrams are very important in representing and explaining ideas in electromagnetism. A challenge is the drawing of three-dimensional objects on a two-dimensional surface, for example the magnetic field around a straight current-carrying conductor and around a coil. From my own experience I knew that drawing a coil on a board is difficult and I discussed this using the diagrams in Figure 4-10.

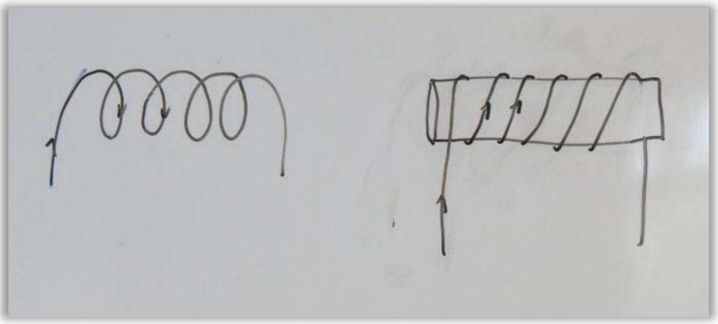


Figure 4-10: Diagrams of coils discussed in theme 5

In the diagram on the left, the direction of the current is ambiguous and students agreed that some learners may perceive the current to be into the board when going downward in the coil and others may see the current as going out of the board, because it is difficult to decide which part of the coil is in front and which part is at the back. I presented the diagram on the right-hand side as a way to sidestep the problem.

After demonstrating the induction of current in a coil by a moving magnet, the idea of magnetic flux and representations that can be implemented when discussing this concept was introduced. The PowerPoint presentation contained a slide that explained the idea of magnetic flux through a loop (Figure 4-11) and a PhET simulation (Figure 4-12) [2] that could be used in an explanation of magnetic flux was also discussed.

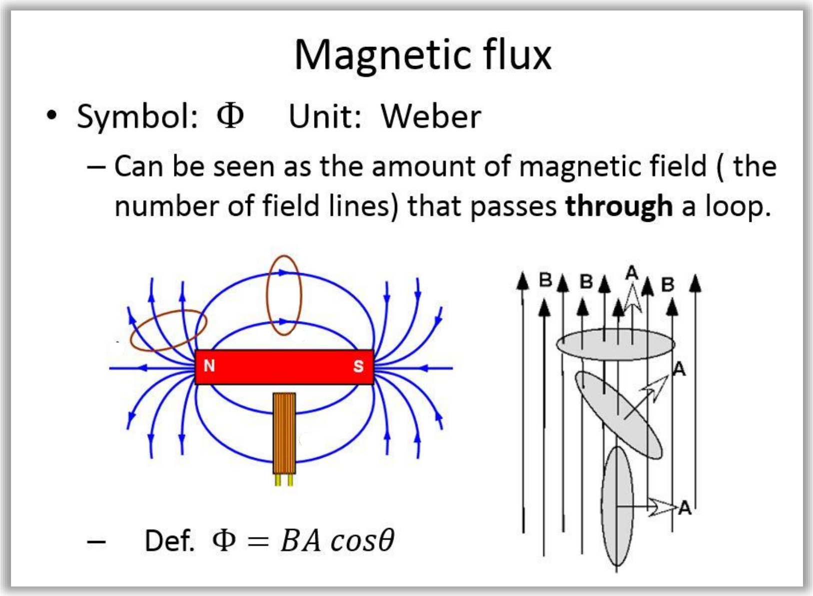


Figure 4-11: PowerPoint slide 7 showing magnetic flux

[2] https://phet.colorado.edu/en/simulations/category/physics/electricity-magnets-and-circuits

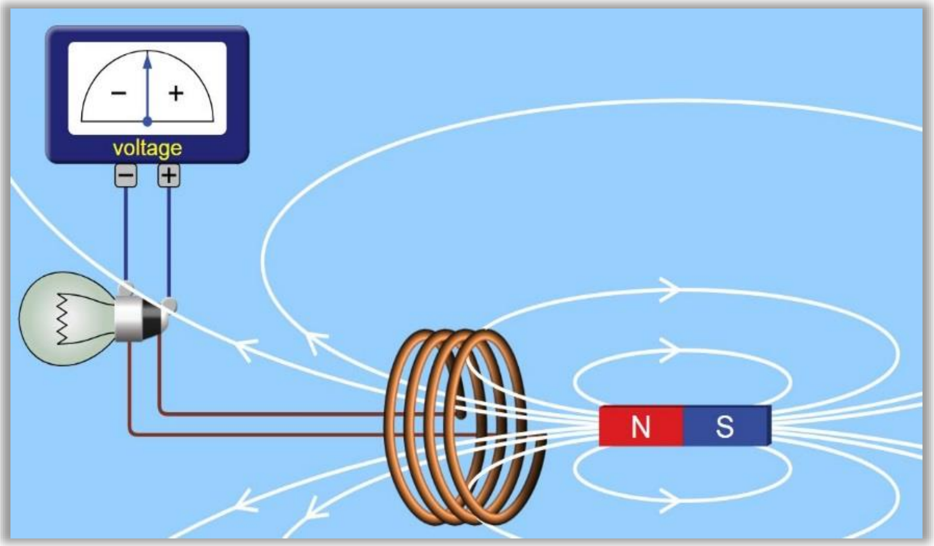


Figure 4-12: PhET simulation used to support the explanation of magnetic flux.

During this session the use of other computer simulations was considered as well. After a few simulations had been shown and discussed, students agreed that simulations are indeed helpful for teaching electromagnetism concepts, in agreement with the findings of Kotoka and Kriek (2014) . The students agreed that one should try to show the actual demonstration first and then show the simulations, since learners know that computer simulations can be modified or "cheated" and they may not trust a simulation if they have not seen the actual phenomenon occurring in real life, realising that a simulation is an idealised situation. Again attention was paid to questions that could be asked during the simulations to guide learners' conceptual development.

4.2.6 Theme 6: Identifying key ideas in electromagnetism (Gr 11)

At this stage students had been exposed to aspects of the content during the previous sessions addressing the components of TSPCK. The rationale behind presenting the theme "selection of key ideas" last was that I expected students to be able to select proper key ideas for teaching electromagnetism after adequate exposure to the content and the sequencing of the concepts.

Once again, this session did not proceed in the way I anticipated. Although there was an improvement in their knowledge about the content and the teaching thereof they still lacked confidence and insight. At the time I reflected:

During the previous sessions, I became aware that the lack of content knowledge still hindered students' appreciation of the importance of the components of TSPCK, because they are focussed on organizing their own prior knowledge about electromagnetism and filling the gaps rather than thinking how to teach the topic.

This observation, regarding the lack of CK and the development of PCK, is in line with a finding by Mavhunga, Ibrahim, Qhobela, and Rollnick (2016). When prompted, the students selected the two headings in the CAPS document as key ideas and added the RHR as a third key idea, as they did in their initial CoRe. In general they did not, at that stage, consider magnetic flux as an idea that is central to understanding the electromotive force (emf) induced in a coil or a loop. During this session students were encouraged to think about the importance of the concept of magnetic flux in the curriculum and about the sequencing of topics to improve the understanding of electromagnetism. At that stage I wrote:

I felt that students started to realise that a discussion of magnetic induction as a physical phenomenon and magnetic flux as a concept to explain induction can be explained before they talk about Faraday's law and use it in solving problems.

4.2.7 Theme 7: Identifying key ideas in electrodynamics (Gr12)

Understanding that magnetism Gr 10 and electromagnetism Gr 11 culminate in teaching and learning about generators and motors in Gr 12, is an important aspect of the knowledge about the curricular saliency of the topic. In my reflection about this session I wrote:

It seemed as if the students grasped for the first time the necessity of addressing the concept of forces acting on a current-carrying conductor in a magnetic field explicitly rather than the cursory way it is addressed in the curriculum.

In this session students were alerted to the challenges when teaching this topic as well as possible teaching strategies when using computer simulations.

4.2.8 *Theme 8: Putting PCK into practice: Lesson design and presentation*

In this session the students had to finalise the mid-intervention CoRe they were constructing for the topic they had chosen and plan and present a lesson based on these CoRes. When they presented the lessons it was evident that students made a genuine attempt to use representations effectively. Reflecting on the lessons gave them the opportunity to assess the effectiveness of their attempts. See for example student AW's mid-intervention CoRe (Figure 4.13), indicating his strategy to explain that when a magnet is cut it two, each of the parts still have a north and a south pole. During his lesson, however, the analogy of a road was not well understood by his peers, and he had to accept that it was not effective.

D2. What questions would you consider important to ask in your teaching strategy?	The representation will be given on the board of the road and then I will ask learners to which town the road leads, no matter where you are on the road.
E. Representations	
E1. What representations would you use in your teaching strategy?	I will use a road from one town to another. I will represent the road on the board, then I will close a piece of the road and ask the learners where does the road lead. Does it still go to the same town, because you cannot just go to one town on one piece of road, because the road points in two directions, and just because we are focusing on a little piece it is stilling going to the same place.

Figure 4-13: Extract from student AW's mid-intervention CoRe

Student MS (Figure 4-14) indicated in her CoRe the use of the representations discussed in theme 3 and included one that was not discussed in the intervention, namely a representation to show that a magnetic field is three-dimensional.

E1. What representations would you use in your teaching strategy?	A bar magnet, paper, and iron filings to repeat what was done in Gr.9. I would then add compasses around the bar magnet to show the direction of the field lines. I would also try to use a polytop of iron filings and a strong magnet to show the 3D characteristic of a magnetic field.

Figure 4-14: Extract form student MS's mid-intervention CoRe

The lesson designs and micro-lesson presentations were not part of the data set collected to answer the research questions. Nevertheless, assessing the lesson designs and lesson presentations of students gave me the opportunity to establish whether students were able to translate the knowledge about teaching electromagnetism in their own practice in a micro lesson situation. Based on my personal perception and reflection, on the micro-lessons and mid-intervention CoRes I concluded that the students had attained knowledge about teaching electromagnetism during the intervention. However, an analysis of the CK tests and the pre-and post-intervention CoRes constructed by the students had to be analysed to provide evidence of the extent to which the intervention contributed to the development of their TSPCK.

4.3 Summary

In this chapter, I reported how the intervention unfolded in terms of themes linked to my theoretical framework. I indicated what the focus of each session was and attempted to show the reader how the discussions and student responses revealed their existing and evolving knowledge of teaching the topic of electromagnetism. The purpose of this and any other methodology module is to prepare pre-service teachers for teaching their subject, of which the first experience is normally during teaching practice as a student. For this reason, I interviewed some of the participants after they had completed their fourth-year teaching practice module to determine what their perceptions were of the extent to which the intervention supported their practice. Information gained from these interviews will be discussed in Chapter 6.

Chapter 5

Pre- and post-intervention assessments: Results, analysis and interpretation

Towards the beginning and at the end of the intervention the participants wrote a CK-test and completed a personal CoRe about electromagnetism. These two assessments are referred to as the pre- and post-CK test and the pre- and post-CoRe. In this chapter the selection of items for the CK test and how these items relate to the school curriculum will be described. A quantitative analysis of the students' performance in the tests and the CoRes will be discussed and I will also reflect qualitatively on the responses to the items in both CK tests and CoRes.

5.1 Introduction

In a paper reviewing research about PCK, Kind (2009) indicated that sound content knowledge (CK) is a prerequisite for quality teaching but "that [it] is only part of the story" (p. 170). That CK only contributes partly to the PCK of a teacher is confirmed in studies by Rollnick et al. (2008) and Davidowitz and Potgieter (2016). The latter established that for a cohort of 89 participants teaching organic chemistry at Gr 12 level, approximately 44% of the variance in their PCK could be accounted for by the variance in their CK about the topic. Although it is widely accepted that a good subject specialist is not necessarily a good teacher it is necessary to heed what Shulman reiterated quite recently (Shulman, 2015): good CK matters indeed.

Although CK was not explicitly taught during the intervention, the curriculum topics of magnetism and electromagnetism were used as a vehicle to teach TSPCK through the study of the five components in the framework (§2.4). The data collected had the purpose of establishing the change in CK as well as TSPCK about electromagnetism in order to answer my first research question:

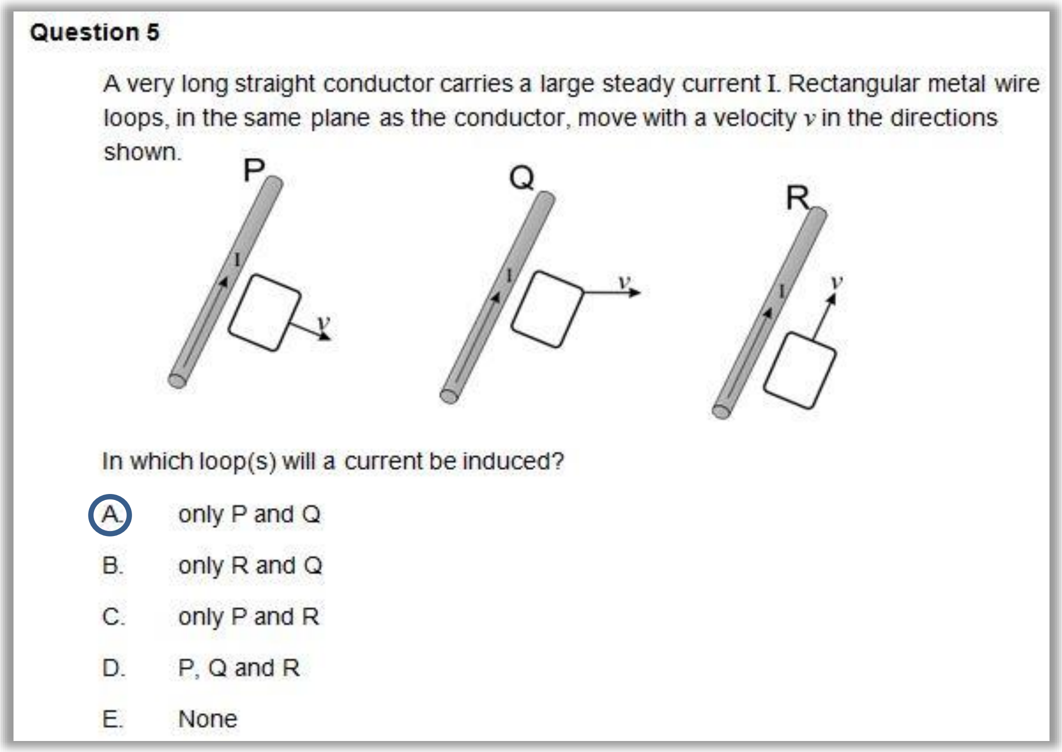
- What is the impact of an intervention, focussing on the components of TSPCK, on the level of CK and PCK of pre-service teachers in electromagnetism?

5.2 The content knowledge test

It was not the purpose of this research to design a validated and standardised CK test for electromagnetism. The purpose of administering a CK test was merely to gauge the background CK of the students against which their PCK was assessed. However, it was necessary to establish the quality of the test used to be able to make reliable inferences.

5.2.1 The design of the CK Test

To compile the CK test I used primarily items from existing tests, namely the Conceptual Survey of Electricity and Magnetism (CSEM) designed by Maloney et al. (2001) and a test designed by Sağlam and Millar (2006). I also included items that were used for diagnostic assessment during my years of teaching school-level and undergraduate Physics. The resulting CK test was a multiple choice test consisting of 14 main items of which a few had sub-items, resulting in a total of 24. For piloting, the CK test was administered to a group of pre-service teachers doing a postgraduate certificate in teaching at another institution than the one where the research was done. Seven pilot tests were received back and after the piloting, changes were made to the diagrams and wording of the initial test. The complete, final CK test can be seen in Appendix F. A typical example of a test item is seen in Figure 5-1.


Question 5

A very long straight conductor carries a large steady current I. Rectangular metal wire loops, in the same plane as the conductor, move with a velocity *v* in the directions shown.

In which loop(s) will a current be induced?

A. only P and Q

B. only R and Q

C. only P and R

D. P, Q and R

E. None

Figure 5-1: Question 5 from the CK Test (correct response indicated)

Table 5.1 shows the origin of the items included in the CK test, the concepts assessed by each item and the grade in which those concepts appear in the FET curriculum (Department of Basic Education, 2011) (see appendix A).

Table 5-1: Content knowledge test: Selection of items

In the table abbreviations mean the following:
S&M: Saglam and Millar (2007)
M et al.: Maloney et al. (2001)

Item number	Source of item	Concept assessed	Grade	Comments
1.1	S&M item 1 Similar to M et al. item 26	The direction of a magnetic field around a straight current-carrying wire	11	
1.2	Own item	The direction of a magnetic field around a straight current-carrying wire	11	This item is similar to item 1.1, with the direction of the current reversed and compasses replacing the arrows. The rationale behind this is to assess whether students are aware that compasses point in the direction of the magnetic field.
2	Own item	The direction of a magnetic field around a current-carrying coil.	11	This item assesses the same concept as 1.1 and 1.2 using a coil.
3.1, 3.2, 3.3	S&M item 12 Similar to M et al. item 31	Charge distribution on a metal bar in a uniform magnetic field	Not in school curriculum	These items do not assess concepts included in the curriculum, but rather pre-knowledge that learners should have regarding induced emf.
4.1, 4.2, 4.3	S&M items 7a),b) and c)	Factors affecting the magnetic flux through a loop or coil.	11	
5	M et al. item 30	The magnetic field around a current-carrying conductor combined with change in magnetic flux and induction.	11	Students need to understand that the magnetic field around a conductor is uniform at a constant distance from the wire and that a current will be induced in the loop when the magnetic flux through the loop changes.
6	M et al. item 29	Current is induced in a loop when the magnetic flux changes, combined with factors that affect magnetic flux.	11	
7	Own item	Current is induced in a loop only when the magnetic flux changes.	11	Students should realise that moving the loop though a uniform magnetic field does not change the magnetic flux through the loop.

Item number	Source of item	Concept assessed	Grade	Comments
8	Own item	The magnetic flux changes when the area of the loop changes and Lenz's law	11	
9	Own item	Principle on which a generator operates; application of Lenz's law	12	
10.1 and 10.2	S&M item 9	Change in magnetic flux and induced emf when a coil moves in and out if a magnetic field	11	This item combines principles addressed by Faraday's law and Lenz's law.
11.1, 11.2, 11.3, 11.4	Adapted from S&M item 2	Force on a current-carrying wire in a magnetic field	12	Students need to be able to apply a RHR to determine the direction of the force on the conductor. See comment for item 13.
12	S&M item 4	Forces on the sides of a current-carrying rectangular loop, producing a torque on the loop.	12	The question is related to the principles on which an electric motor works. See comment for item 13.
13.1, 13.2	S&M item 5	Lorentz force: Charge at rest in magnetic field does not experience a force	12	This concept is not explicitly included in the curriculum, but is implied as pre-knowledge to understand the force on a current-carrying conductor.
14	S&M item 6	Lorentz force	12	This concept is not explicitly included in the curriculum, but is implied as pre-knowledge to understand the concept of a force on a current-carrying conductor.

The CAPS curriculum prescribes only two main topics in electromagnetism Gr 11; *the magnetic field associated with current-carrying conductors* and *Faraday's law*. In the Gr 12 curriculum, a study of generators and motors is expected. The curriculum refers to the following sub-concept related to the understanding of electric motors (Department of Basic Education, 2011, p. 130): "Explain why a current-carrying coil placed in a magnetic field (but not parallel to the field) will turn by referring to the force exerted on moving charges by a magnetic field and the torque on the coil." No reference is made in the Gr 11 curriculum to the force experienced by a charged particle moving though a magnetic field, the force experienced by a current-carrying conductor in a magnetic field and the torque on a current-carrying loop inside a magnetic field. As such, the curriculum does not expect explicit explanation of the force on a current-carrying wire in a magnetic field which is the result of the interaction between the external magnetic field and the magnetic field around the wire. Although this concept is not in the Gr 11 curriculum, it is expected that student teachers should have knowledge about this, since it is part of the first-year Physics curriculum, and for this reason questions about the Lorentz force were included in the CK test.

5.2.2 Results of the pre- and post-CK tests

The raw scores of the pre-and post-CK tests are given as percentages in Table 5.2, ranked in order of increasing normalised gain. The average of the pre-test was 37.2% and improved to 64.9 % in the post-test. Since it is a lesser challenge for students who performed poorly in the pre-test to improve in the post-test than for students who were the highest performers in the pre-test, the normalised gain (Hake, 1998) is a better indication of the improvement of a student. Normalised gain is the actual gain divided by the maximum possible gain. Compare, for example, students NL and NB, where the actual improvement of student NL is 63% and for student NB it is 42%. Since student NB improved from a higher initial mark, her normalised gain is higher. All but three of the students showed an improvement in CK after the intervention as measured by this CK instrument. The two students with negative normalised gain had a record of poor class attendance and did not receive the full benefit of the intervention. It is also interesting to note that the level at which a student passed undergraduate Physics is not a good predictor of performance in the pre- or post-tests. However, only limited information can be gained from this analysis and further investigation by Rasch analysis, where the participants and the test items will be placed on the same continuum, will give more scope for interpretation.

Table 5-2: Results (raw scores) of the pre- and post-CK tests

Number (as referred to in the Rasch analysis)	**Student**	**Gender**	**Level of under-graduate Physics**	**First language English speaker**	**Pre-test % Ti**	**Post-test % Tf**	**Actual gain Tf − Ti**	**Normalised gain $\frac{Tf - Ti}{100 - Ti}$**
14	NB	F	3	Yes	54.2	95.8	41.7	0.91
9	HS	M	2	No	37.5	91.7	54.2	0.87
12	NL	F	2	No	16.7	79.2	62.5	0.75
6	MS	F	1	No	50.0	83.3	33.3	0.67
5	DK	M	3	No	25.0	66.7	41.7	0.56
1	AW	M	2	No	37.5	70.8	33.3	0.53
3	HD	F	2	No	37.5	70.8	33.3	0.53
4	JD	F	2	No	29.2	66.7	37.5	0.53
11	MW	F	2	No	45.8	70.8	25.0	0.46
2	BM	M	1	No	62.5	79.2	16.7	0.44
8	KM	F	2	No	20.8	45.8	25.0	0.32
10	LM	M	3	No	41.7	41.7	0.0	0.00
13	TM	M	3	No	37.5	33.3	-4.2	-0.07
7	VS	M	2	No	20.0	12.5	-12.5	-0.17
Average					37.2	64.9	27.7	0.45

5.2.3 Validity and reliability of the CK test

Although the purpose of this study was not to design a validated test that could be used in future with individuals or larger groups, some validity and reliability checks had to be done before meaningful inferences could be made from the results. A Rasch analysis, as described in chapter three, was done on the pre- and post-CK tests of the 14 participants. For the analysis of the pre- and post-test the data was stacked, as explained in §3.6 (Cunningham & Bradley, 2010; Wright, 2003), effectively increasing the number of persons to 28. The reasoning behind this is that the test items were exactly the same before and after the intervention and were therefore entered in the data file as one test, whereas the participants were entered as two sets of persons, because the assumption was that the intervention "changed" the students as far as their PCK and CK about electromagnetism were concerned. To be able to separate the pre-and post-tests in the data analysis a person factor "Pre or Post" was allocated to the "two sets" of participants. Aspects that were considered to determine the validity of the test are discussed below.

Overall fit

The χ^2 probability value of 0.30 that was obtained is more than a significance level of 0.05 and therefore the null hypothesis that the items and the sample fit the Rasch model is accepted. The Rasch analysis software RUMM2030 provides item and person statistics that give information about the extent to which a particular person or item fits the model. Item and person fit residuals indicate how the observation deviates from the model expectations. A fit residual of zero and a standard deviation (SD) of 1.0 would reflect perfect fit (Salkind, 2006).

The summary statistics for the stacked CK tests are given in Figure 5-2 and show good overall fit for items and persons with an item fit residual of -0.114 and SD of 0.75 and person fit residual of -0.103 and SD of 0.75.

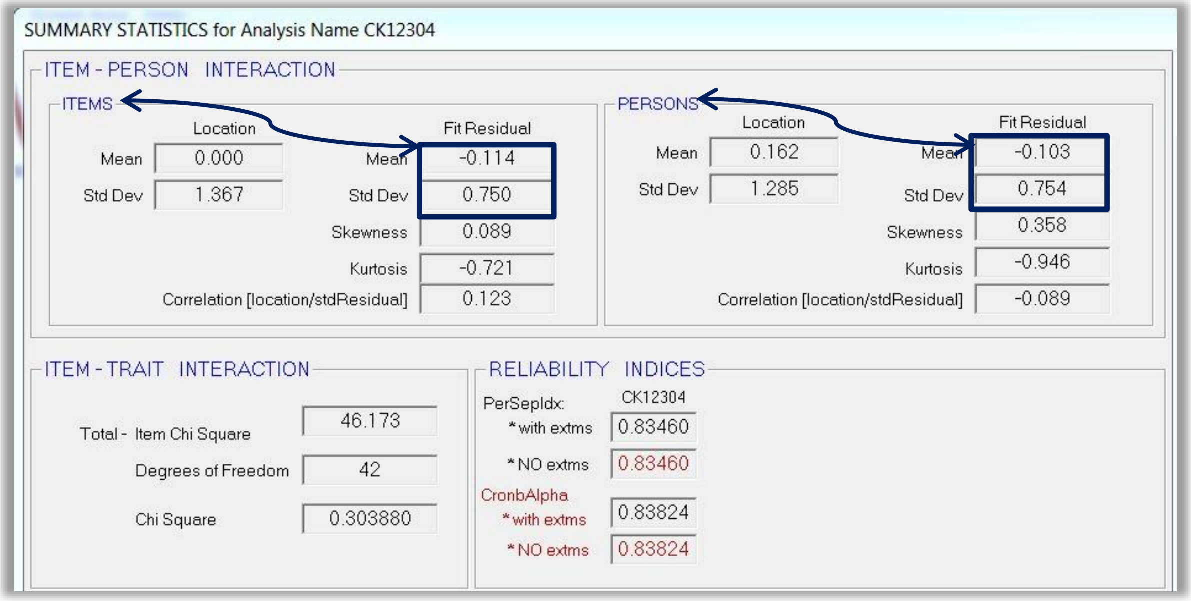


Figure 5-2: Summary statistics for CK test with stacked data

The RUMM software also provides individual item and person fit residuals. A residual is the difference between the expected value and the observed value for a particular person or item. In the RUMM software, these values are set to be highlighted when they fall outside the -2.5 to 2.5 interval. A value outside this interval will indicate substantial deviation from the model. With individual person fit residuals between -1.35 and 1.36, there are no misfitting persons in the sample for the CK test analysis.

The individual item fit residuals are between -1.47 and 1.35 as can be seen in Figure 5-3, indicating that all items behave as expected by the model when the data was stacked.

INDIVIDUAL ITEM-FIT for Analysis Name CK12304 - Item-Person Fit Residual [Ascending Order]

	Seq	Item	Type	Location	SE	FitResid	DF	ChiSq	DF	Prob	F-stat	DF-1	DF-2	Prob
21	10021	ST21	Poly	1.025	0.461	-1.472	25.57	3.630	2	0.162853	...	...	...	...
3	10003	2	Poly	0.253	0.435	-1.447	25.57	3.731	2	0.154824	...	...	...	...
18	10018	12	Poly	0.264	0.435	-0.820	25.57	4.979	2	0.082935	...	...	...	...
6	10006	4.1	Poly	-1.809	0.538	-0.814	25.57	4.309	2	0.115964	...	...	...	...
17	10017	11.3	Poly	-1.319	0.486	-0.550	25.57	1.495	2	0.473528	...	...	...	...
19	10019	13.1	Poly	1.388	0.484	-0.521	25.57	1.662	2	0.435519	...	...	...	...
20	10020	13.2	Poly	1.388	0.484	-0.521	25.57	1.662	2	0.435519	...	...	...	...
1	10001	1.1	Poly	-1.626	0.516	-0.389	25.57	0.775	2	0.678588	...	...	...	...
7	10007	4.2	Poly	-1.057	0.466	-0.305	25.57	1.229	2	0.540811	...	...	...	...
11	10011	7	Poly	0.529	0.440	-0.248	25.57	0.025	2	0.987585	...	...	...	...
4	10004	3	Poly	0.614	0.287	-0.231	25.57	0.546	2	0.761280	...	...	...	...
2	10002	1.2	Poly	-0.431	0.438	-0.215	25.57	1.168	2	0.557621	...	...	...	...
5	10005	3.3	Poly	-3.410	0.907	-0.120	25.57	0.324	2	0.850433	...	...	...	...
8	10008	4.3	Poly	-1.260	0.481	0.080	25.57	1.886	2	0.389398	...	...	...	...
9	10009	5	Poly	1.537	0.496	0.312	25.57	2.207	2	0.331711	...	...	...	...
15	10015	10.2	Poly	1.126	0.467	0.446	25.57	0.862	2	0.649979	...	...	...	...
10	10010	6	Poly	1.701	0.511	0.500	25.57	4.373	2	0.112314	...	...	...	...
16	10016	11.1	Poly	-0.112	0.217	0.657	25.57	3.363	2	0.186060	...	...	...	...
13	10013	9	Poly	0.217	0.434	0.864	25.57	2.684	2	0.261372	...	...	...	...
12	10012	8	Poly	1.596	0.501	1.048	25.57	0.846	2	0.655145	...	...	...	...
14	10014	10.1	Poly	-0.617	0.444	1.351	25.57	4.416	2	0.109942	...	...	...	...

	Location	FitResid		ChiSq	DF
Mean	0.000	-0.114	Totals	46.173	42
Std Devn	1.367	0.750	Total Prob	0.303880	

☑ Highlight extrm FitResid values. Set at: +/- 2.5

Highlight probabilities below   Select Probability Base

Figure 5-3: Individual item fit residuals

Response dependence

High response dependence between two or more items indicates that these items are measuring the same concept too closely and could point to redundancy of items. Response dependence can be investigated by obtaining the residual correlation matrix provided by RUMM (see Figure 5-4, p. 78). The acceptable level of residual correlation was fixed at 0.4, so that all correlations above that would be highlighted.

Correlation between items 3.1 and 3.2 is indicated. This is expected, since these sub-items are both testing application of knowledge of the induced emf across the ends of a metal bar moving through a magnetic field. Although item 3.3 is not included in the indicated correlation, I decided to combine these three items in a sub-test for the purpose of the analysis. Item 3.3 was also not flagged as an extreme item in the stacked data, yet is was a very easy item, answered correctly by 13 out of 14 participants in the pre-test and all 14 participants in the post-test and it was thought appropriate to include the item in the sub-test rather than delete it from the stacked data set. Yet, for the racked data the item was deleted, since it was indicated as an extreme item because all participants answered it correctly.

Person-Item Residual Correlation Matrix

Principal Component Summary | PC Normalised Vectors | PC Loadings | Varimax Rota

Item	1.1	1.2	2	3.1	3.2	3.3	4.1	4.2
1.1	1.000							
1.2	-0.067	1.000						
2	0.069	0.077	1.000					
3.1	0.117	-0.035	0.378	1.000				
3.2	-0.046	0.201	-0.084	0.547	1.000			
3.3	-0.129	-0.230	-0.346	0.052	0.082	1.000		
4.1	-0.030	0.153	0.036	0.114	-0.064	-0.188	1.000	
4.2	0.102	-0.330	-0.163	0.171	0.069	0.291	0.023	1.000
4.3	-0.155	-0.229	0.491	0.203	-0.137	-0.089	-0.005	0.208
5	0.153	0.079	-0.273	0.069	0.037	0.062	0.162	0.211
6	-0.424	-0.043	-0.165	-0.081	0.156	0.069	-0.166	-0.060
7	0.041	-0.143	0.298	-0.163	-0.232	-0.299	-0.209	-0.184
8	-0.356	-0.151	-0.282	-0.218	-0.192	0.075	-0.140	0.078
9	-0.066	0.089	-0.189	-0.278	-0.281	0.107	0.100	-0.052
10.1	0.050	-0.151	-0.177	-0.074	-0.008	-0.080	-0.234	-0.291
10.2	-0.029	-0.126	0.128	-0.099	-0.272	0.094	-0.278	0.155

Figure 5-4: Correlation matrix of some of the items in the CK test

Perfect correlation (with a residual correlation value of 1.00) was shown between 13.1 and 13.2. If the purpose of this exercise was the design of a valid instrument with the sole purpose of measuring participants' knowledge of electromagnetism, the omission of 13.2 would have been considered. In this instance, however, and since the analysis was post hoc, the two items were just combined in a subtest for analysis of the performance of the participants.

Other items that showed correlation were items 2 and 4.3 and also items 8 and 10.2. Items 2 and 4.3 assessed different concepts and no obvious reason for the correlation could be found. Items 8 and 10.2 tested understanding of related concepts in different scenarios. It was decided to leave these four items as they were, because such correlations in a small sample may not be significant, especially when no obvious reason for correlation can be found. When a larger sample is used and such correlations persist, closer investigation into the reasons for this should be undertaken.

Unidimensionality and differential item functioning

An assumption of the Rasch model is that the instrument is unidimensional, meaning that it measures only one construct, in this case the CK about electromagnetism in the FET curriculum. The source and selection of items, as explained above, suggest that this instrument indeed measures what it sets out to measure. One attribute that could have an impact on the outcome of the measurement may be the participants' proficiency in English, since the instrument was only set in English. Whether this is the case could not be established because there was only one first language English speaker in the group.

A unidimensionality and differential item functioning (DIF) analysis would typically give an indication of the invariance of the items to contextual factors such as gender and primary language. In the RUMM software, this could be done by defining grouping variables called person factors. For the reason already mentioned, first language was not used as a person factor. Although gender was not expected to show DIF, an analysis was done with gender as a person factor. In the DIF summary statistics table provided by RUMM no problems were flagged for gender (see Figure 5-5). Furthermore, although the person location mean for females is 0.29 and for males -0.073, the difference is not significant with an ANOVA indicating a p-value of 0.43.

DIF Summary Statistics

		Class Interval				Gender			
No.	Item	MS	F	DF	Prob	MS	F	DF	Prob
1	3	0.13533	0.14110	2	0.869178	0.13973	0.14570	1	0.706343
2	11.1	0.80149	0.69185	2	0.511215	3.57484	3.08581	1	0.092890
3	13	1.30192	0.97294	2	0.393649	3.35714	2.50884	1	0.127480
4	ST004	0.24807	0.37459	2	0.691870	2.41124	3.64100	1	0.069509
5	ST005	0.70530	0.90002	2	0.421010	2.66921	3.40615	1	0.078456
6	ST006	2.02998	3.59608	2	0.044537	0.15320	0.27139	1	0.607607
7	ST007	1.89614	4.51008	2	0.022833	0.44347	1.05481	1	0.315563
8	ST008	0.46047	0.54428	2	0.587873	1.58673	1.87556	1	0.184659
9	ST009	0.88528	0.85637	2	0.438378	0.06745	0.06525	1	0.800759
10	ST010	0.60148	0.49950	2	0.613551	1.03590	0.86027	1	0.363727
11	ST011	1.95023	1.70179	2	0.205498	2.74537	2.39563	1	0.135941
12	ST012	0.06606	0.06941	2	0.933147	1.57151	1.65130	1	0.212147
13	ST013	0.45886	0.27168	2	0.764616	0.70843	0.41945	1	0.523913
14	ST014	0.90096	0.72778	2	0.494250	1.27665	1.03125	1	0.320904
15	ST015	1.86123	1.22337	2	0.313487	2.48544	1.63366	1	0.214520
16	ST016	0.50411	0.45676	2	0.639205	4.34828	3.93982	1	0.059763
17	ST017	0.84886	1.16735	2	0.329733	0.02753	0.03785	1	0.847522
18	ST018	2.49932	4.25019	2	0.027497	0.64162	1.09109	1	0.307572
19	ST019	2.10222	4.39344	2	0.024810	0.25042	0.52336	1	0.477035

Figure 5-5: DIF summary statistics for gender

This concludes the validity and reliability check for the CK test and data can now be used to address the research questions.

5.2.4 Comparison of the pre-and post-CK tests

When the averages of the raw scores of the pre-and post- CK tests (Table 5-2, p.75) are calculated, an improvement, from 37% to 65% is evident. However, the Rasch analysis provides more detailed insight into aspects of the change brought about by the intervention. By stacking the data, that is, placing the pre- and post- student performance along the same continuum, treating the sample as two sets of participants (before and after), the change in performance of each student can be investigated.

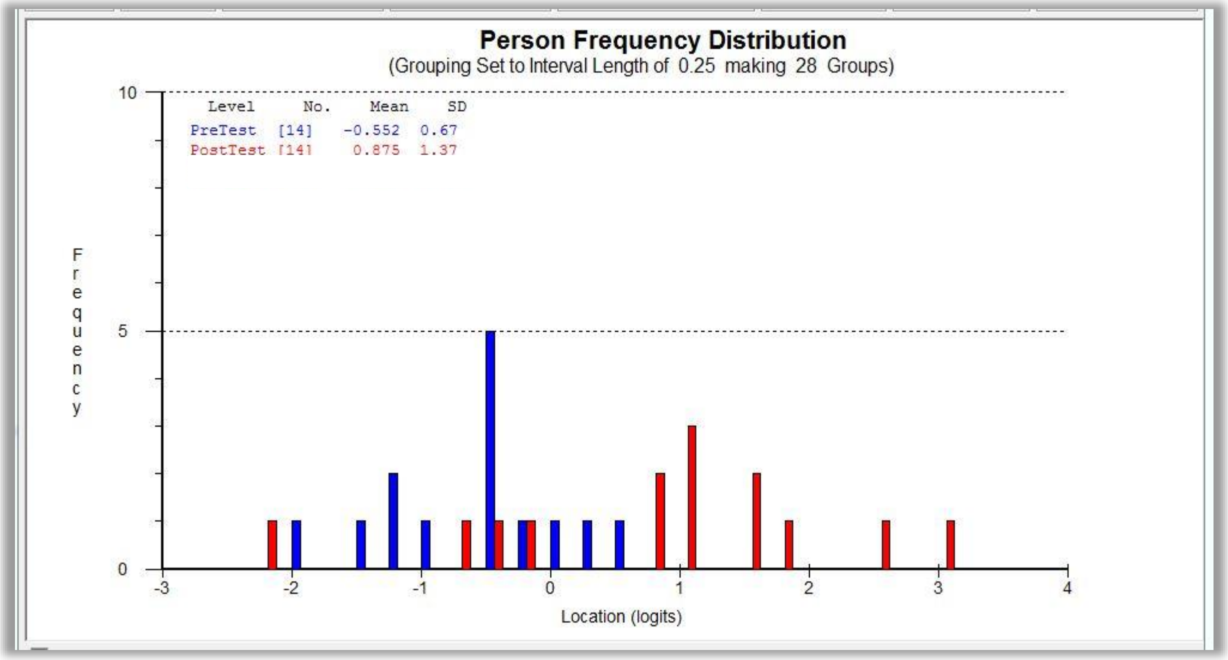


Figure 5-6: Performance in the pre-and post-test compared

Figure 5-6 shows the person-frequency distribution for the performance of individuals in the pre- and post-tests, with the blue bars showing the pre-test and the red bars showing the post-test. An ANOVA of the pre- and post-tests indicated a significant improvement with a p-value of 0.0081. Since the participants had no exposure (known to the researcher) to the content other than the discussions during the intervention, it can be assumed that this improvement can be ascribed to the intervention. The class attendance of students VS and TM (see Table 5.2, p.75) was poor and they did not receive the benefit of the intervention, which is reflected in their poor performance in the post-test.

The graph in Figure 5-7, obtained from the stacked data shows how individuals performed in both CK tests in order of decreasing performance in the pre-test. This graph does not show actual marks or percentages for student performance, but the person locations (indicating the person's ability) established by the Rasch analysis. It is evident that all but three students improved after the intervention. The average person location in the pre-test is -0.55 with a SD of 0.67 and the average person location for the pre-test is 0.88 with an SD of 1.37. In the pre-test the person abilities are less spread out than in

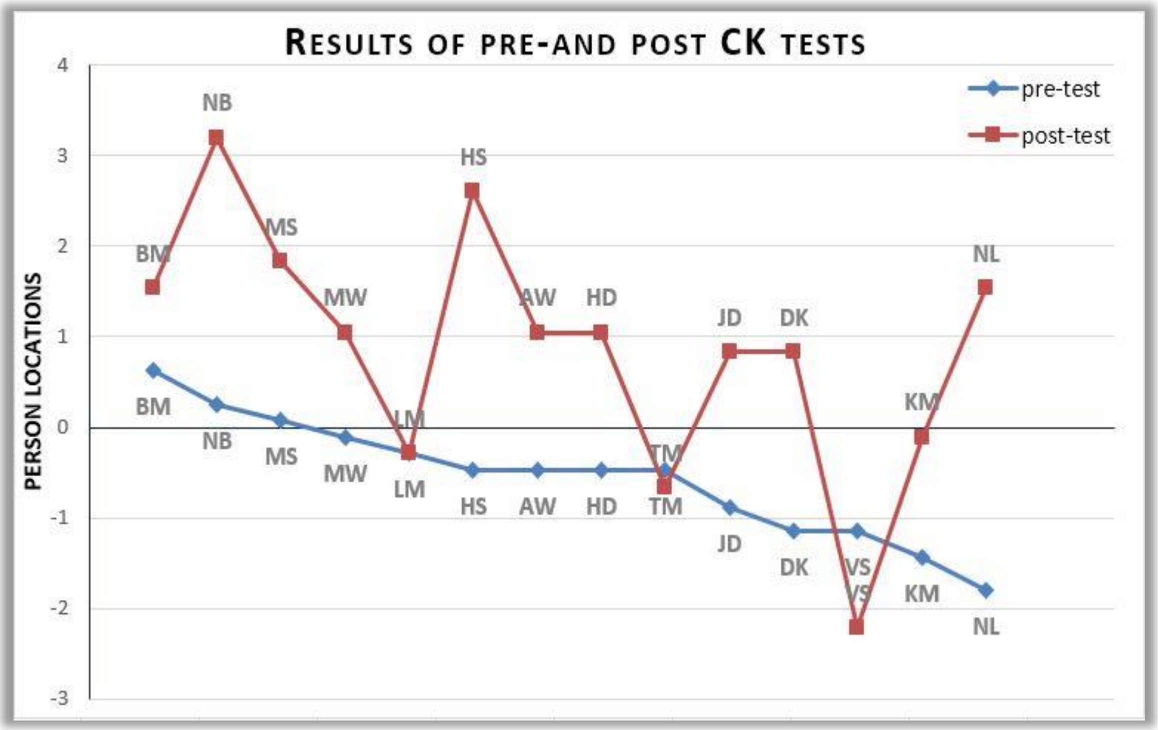


Figure 5-7: Results of the pre-and post- CK tests in terms of person locations

the post-test, showing that some students' ability improved more than average and some less than average after the intervention. As a case in point, student LM was located fifth compared to the rest of the class during the pre-test and twelfth in the post-test. Thus, it can be concluded that the performance in the pre-test was not a predictor of performance in the post-test. An interesting feature of this analysis is that it establishes that exactly the same improvement in the raw score of two students does not indicate the same improvement when the results of the pre-and post-tests are placed on the same ruler. Both students DK and NB showed an improvement of 41.7% in their raw scores, yet student DK showed an improvement in person location of 1,8 while student NB showed an improvement of 2.7. Student NB showed an improved ability to answer the items with higher difficulty, whereas student DK could still not get those items right.

The relative difficulty of items of both tests in relation to the abilities of the students is shown in Figure 5.8. This map was obtained by racking the data of the two tests in order to compare how the item difficulties changed as experienced by students before and after the intervention. A person with average ability has a 50% change of getting the item at the 0.00 item location right. Such a person will have a higher chance of getting the items below 0.00 right. In general, it shows that the items at the bottom of the diagram are experienced as easy by the average student and the ones at the top of the diagram as difficult. To distinguish between the items of the two tests, the pre-test items were all labelled with an A preceding the number of the item and those of the post-test with a B. At a first glance it is evident that the students experienced the post-test items (circled in red) as easier than those in the pre-test. All but three of the post-test items lie at or below the 0.00 item location.

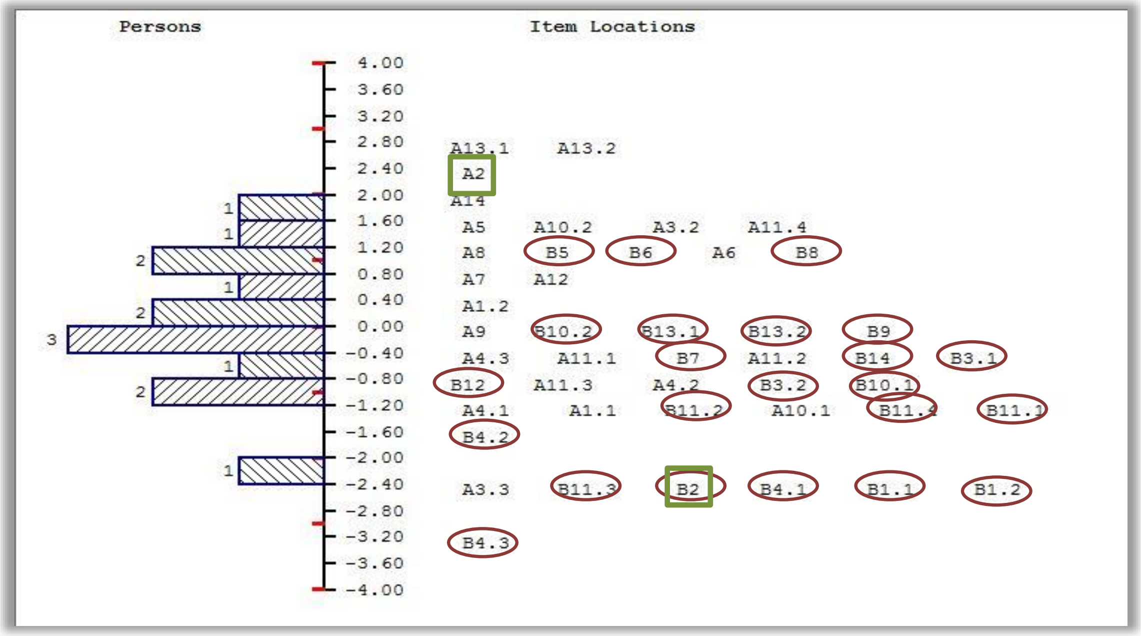


Figure 5-8: Person-item map for the racked CK test data

The most pronounced change is the way students experienced item 2 (marked with a green square). This can also be seen in the bar graph (Figure 5-9) showing the frequencies of the responses to the items in the two tests. Changes in the way students responded to item 2 will be discussed in the next section.

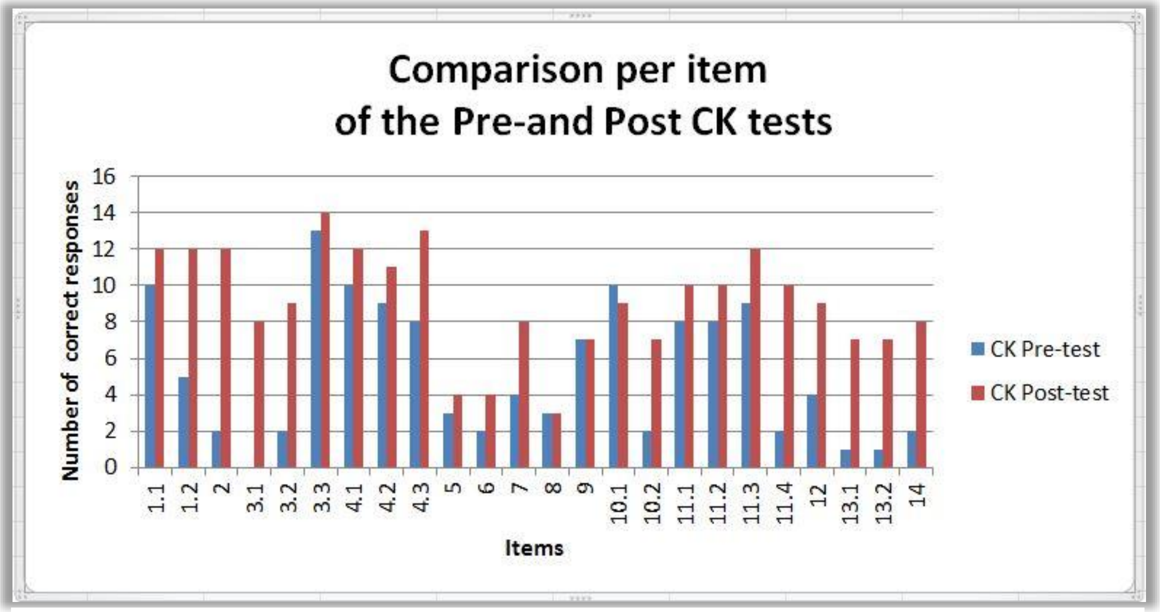


Figure 5-9: Frequencies per item of correct responses in the pre- and post-tests

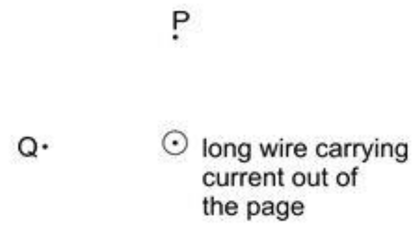
Item A3.1 (pre-test) was answered incorrectly and B3.3 (post-test) was answered correctly by all students. For this reason these items were indicated as extreme in the racked data, and were deleted from the racked analysis. For the stacked data these two items were not deleted but combined in a subtest together with item 3.2, as explained earlier. Items 13.1 and 13.2 proved to be very difficult in the pre-test and were answered correctly by only one student. These items moved down to items of average difficulty in the post-test.

5.2.5 Qualitative look at the CK tests

In this section I will take a closer look at the items that underwent the most pronounced or interesting changes from pre- to post-test. The reader is again referred to Appendix F for a complete version of the CK test. The pre- and post-CK tests were exactly the same test. As discussed in Chapter 3 (§3.6), this enabled a Rasch analysis of stacked CK test data so that the performance of students could be tracked over time. Care was taken not to discuss or refer to test items explicitly during the intervention, to avoid as far as possible students answering the post-test correctly from memory. The only diagrams that were used in the test and repeated in the intervention were those in questions 2, 3 and 11. These diagrams needed to be included in the discussion of representations that can be used when teaching electromagnetism.

It was expected that items 1.1 and 1.2 (Figure 5-10, p. 84) would show strong correlation in the Rasch analysis, since these two items assess the same concept, namely the magnetic field around a current-carrying wire. In both items the orientation of the wire is perpendicular to the page and in both items the respondent had to indicate the direction of the magnetic field around the wire. In 1.1 the direction of the current was out of the page surface and options were given with arrows or words indicating a possible direction of the magnetic field. In 1.2 the current was into the page surface and the option consisted of different orientations of compass needles. Surprisingly, in the pre-test six students had 1.1 correct but not 1.2, with three choosing option C and three choosing option D. A reason for students choosing option C could be that they did not realise that compasses point in the direction of the magnetic field, something the students themselves mentioned as a possible misconception during the discussion of theme 6 of the intervention. This confusion did not persist in the post-test.

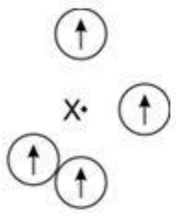
1.1 The diagram shows a long straight wire, perpendicular to the plane of the paper. The current in the wire is upwards out of the paper. The points P and Q are the same distance from the wire.



What is the direction of the magnetic field at points P and Q?

	Direction of the magnetic field at P	Direction of the magnetic field at Q
A	↓	→
B	←	↓
C	↑	←
D	→	↑
E	into the page	into the page
F	out of the page	out of the page

1.2 The diagram shows four compasses that are placed on a flat surface. They are orientated as shown because of the earth's magnetic field. (Question continues on next page)



A wire carrying current into the surface, is placed through a hole in the surface at point X between the compasses so that the wire is perpendicular to the plane. Which diagram below shows best the orientations of the compasses with the current carrying wire at rest in position as shown?

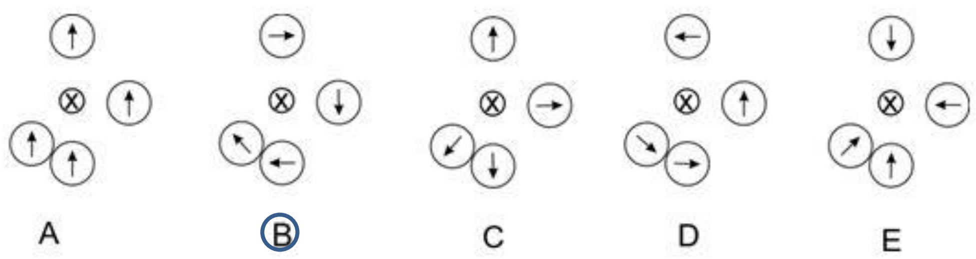


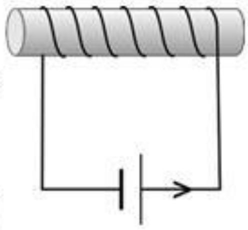
Figure 5-10: Item 1 from the CK test. Correct answers indicated

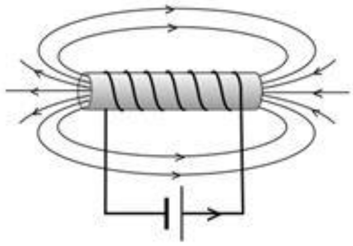
As indicated earlier, item 2 (Figure 5-11 p.86) showed a pronounced change after the intervention. This item tests knowledge about an idea fundamental to many other concepts in electromagnetism at school level, namely the magnetic field around a current-carrying coil. Only two students answered the question correctly in the pre-test, with seven students choosing either B or D as their answers, probably confusing the field around a straight wire with the field around a coil. The diagram used in this question was often used as a representation during the intervention. This may have contributed to the fact that the item was experienced so differently in the post-test from the pre-test.

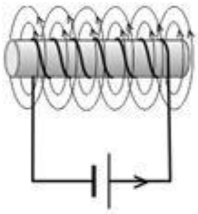
Items 3.1 and 3.2 (Figure 5-11 p. 86) proved to be very difficult in the pre-test. By far the most common choices for these items were either B or C for 3.1 and D or E for 3.2. Most students had no idea of the concepts that play a role in the induced emf across the ends of a metal bar. There seemed to be better understanding of this concept after the intervention. The students also had difficulty in answering items 5, 6 and 8 in both tests (see Appendix F). These items assessed the understanding of the existence and/or direction of induced current in a loop in different scenarios and required integration of more than one concept. However, no response correlation was indicated by the Rasch analysis, meaning that a student who had one of these items correct did not necessarily have the others correct as well.

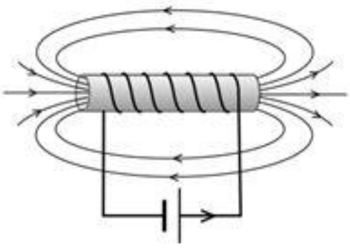
Question 2

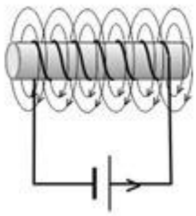
A wire coil is wound around a tube and is connected to a cell. It carries current as shown. Choose the diagram that best represents the magnetic field around the coil.



(A) 

B 

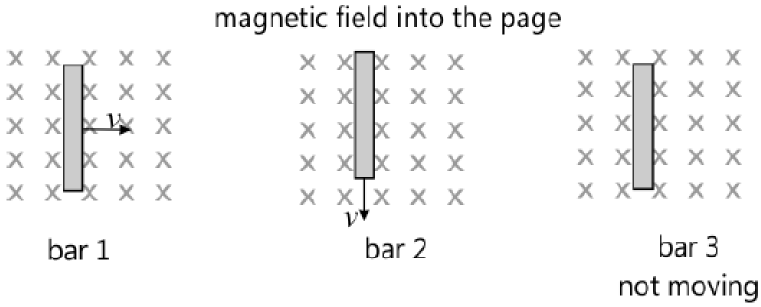
C 

D 

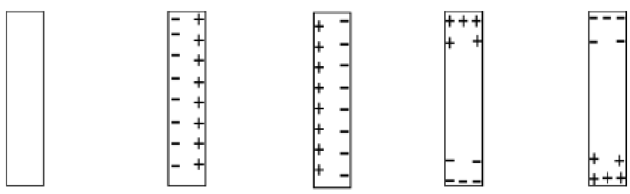
E There is no magnetic round the coil, only an electric field.

Question 3

Three identical metal bars are in magnetic fields with the same magnitude. The direction of the field is into the page. Bar 1 and bar 2 are moving with constant speed in the directions shown and bar 3 is at rest.



Use the following options to answer questions 3.1, 3.2 and 3.3.



A B C D E

3.1 Which diagram shows the charge distribution in bar 1? **D**

3.2 Which diagram shows the charge distribution in bar 2? **B**

3.3 Which diagram shows the charge distribution in bar 3? **A**

Figure 5-11: Items 2 and 3 from the CK test, answers indicated

For the item characteristic curves (ICC) displayed by the RUMM software (Figure 5-12), the persons are grouped in class intervals along the person-location axis. The value on the vertical axis is an indication of the probability of getting the answer right by a participant at a specific person location, with the grey curve showing the expected values (higher probability of correct answers for higher person locations). For the current analysis RUMM chose, by default, three class intervals, with nine in the first class interval (lowest ability), nine in the second and ten in the third (highest ability), adding up to a total of 28 which is the number of persons for the stacked data (14 for the pre-test and 14 for the post-test). Since the three class intervals were chosen to include all 28 persons, none of the students was included in the high ability group for the pre-test. The ICC for item 6 is shown in Figure 5.12; the ICC curves for items 5 and 8 look similar. The plot shows that the correct answers in the pre-test came from the students in the low ability group (located at the low person-location range), which may indicate that students guessed the answer. These students gave incorrect answers in the post-test, whereas some students from the high-ability group answered the items correctly. Since items 5,6 and 8 required critical reasoning and integration of more than one concept, the outcome may suggest that the students' ability to reason critically to solve problems was not developed during the intervention.

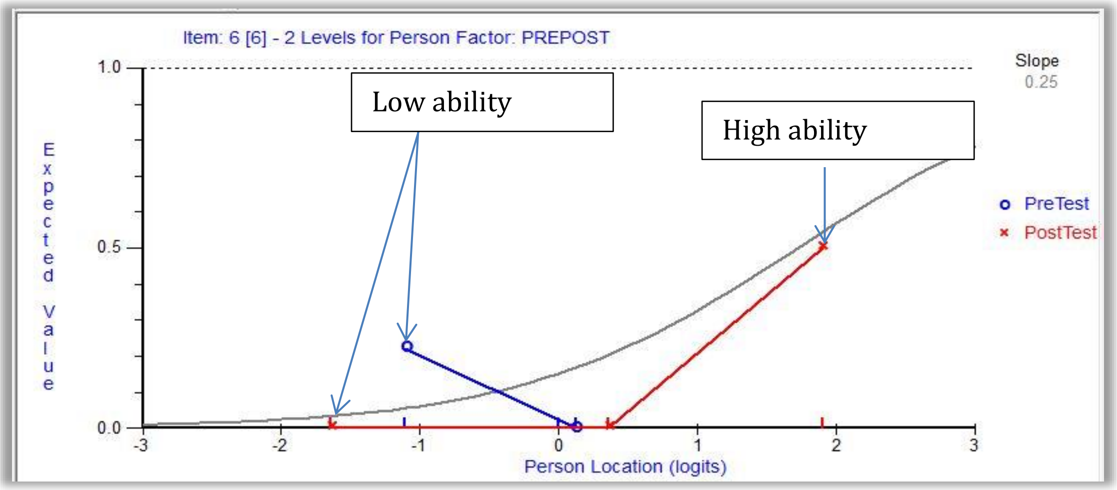


Figure 5-12: Item characteristic curve for item 6 for the stacked data.

Item 13.2 was answered correctly by the same students who answered item 13.1 correctly and one could argue that item 13.2 is redundant, because it does not give any extra information about the ability of respondents. Since the sample is so small and a different response pattern may occur in a larger sample, item 13.2 was not deleted but combined post hoc with 13.1 in a subtest as item 13. The ICC for item 13 is shown in

Figure 5-13. The low-ability group could not get this item right in either of the tests, whereas the average and high ability groups performed better in this item after the intervention, even though the high-ability group did not perform as expected (the continuous curve indicate the expected values). The improvement here may be linked to the representations introduced during the intervention: a demonstration with a cathode-ray tube showing the force experienced by a beam of electrons in a magnetic field and the diagrams used when discussing the force on a current-carrying conductor.

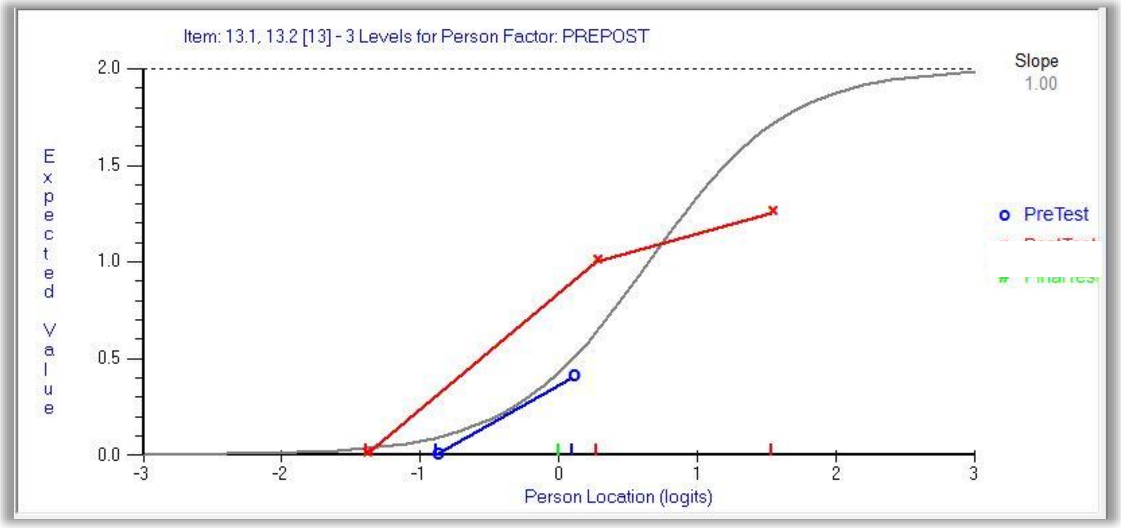


Figure 5-13: ICC for item 13 for the stacked data

The higher SD value for the post-test data in Figure 5-7 (p.81) and the information gained from the ICC's give an indication that the intervention had the effect of separating the low- and high-ability groups in terms of their performance.

5.3 The CoRes

During the same sessions that the pre- and post-CK tests were written, the participants also constructed pre- and post-intervention CoRes, referred to as the pre- and post-CoRes. These were assessed and the marks counted towards their final mark for the module. On both occasions the students had access to the national curriculum statement in the CAPS document and there was no time restriction for the completion of the CoRes. The students were instructed to identify three key ideas specifically for Gr 11 electromagnetism and to construct the CoRes in the sequence they would teach these key ideas. Since the participating pre-service teachers were students at the beginning of their fourth year with no formal teaching experience, the assumption was that the initial CoRes of these students would reveal that they were not thinking about the topic in terms of teacher knowledge yet, which concurs with remarks by Hume and Berry (2011) and Mavhunga (2014). The post-CoRes were expected to reveal changes in students' knowledge and thinking about the teaching of electromagnetism.

5.3.1 Scoring of the pre- and post-CoRes

A rubric for quantifying TSPCK as captured by CoRes was designed for the purpose of scoring (see Appendix G). The responses of the students to the prompts in the CoRe tool were considered and one of the levels - limited, basic, developing or exemplary (Park et al., 2011) - was assigned to each response. Descriptors that clearly distinguished between the four levels of knowledge about the different aspects of teaching electromagnetism had to be formulated. Other similar rubrics designed by Rollnick and Mavhunga (2014) for CoRes that pre-service teachers constructed on chemical equilibrium and for CoRes on electricity by Mavhunga and others (Mavhunga et al., 2016) were consulted and used as a guideline.

The expert CoRe for Gr 11 electromagnetism (Appendix H), discussed in § 6.2.3.1, was regarded as an extensive but not exhaustive portrayal of the PCK about electromagnetism belonging to the profession (canonical PCK) as described in the conceptual framework (§ 2.4). As explained earlier, the expert CoRe served as an example of exemplary TSPCK. When assessment and scoring of participants' CoRes took place, scope was allowed for other approaches and interpretations. The three key ideas selected by the participants were compared to the expert CoRe when its appropriateness was considered and a level was allocated. Knowledge about selection of key ideas was assigned the code A0 in the analysis. The following principles were applied during the scoring of the CoRes:

Student responses	Principle applied when scoring
The student made a poor selection of key ideas	A participant was penalised for poor selection of key ideas (Prompt A0 in the CoRe template), but the rest of the responses belonging to the inappropriate key ideas were considered separately for their own value.
Responses to subsequent prompts were of different levels for the three key ideas.	The score that was assigned was for the response that revealed the highest level of knowledge.
A student responded to a specific prompt for only one of the key ideas.	The response was scored and assigned to that prompt. "Empty blocks" were not regarded as missing data.
A student did not respond at all to a certain prompt for any of the key ideas.	The student was scored limited. The notion was that even if a student chose for whatever reason, not to respond to a certain prompt, one could not assume that the student had no knowledge of that aspect of teaching the topic.
A student revealed poor conceptual knowledge in the responses.	The score for that prompt was lowered by one level.
The student revealed knowledge in the last two prompts.	The last two prompts in the CoRe tool that was administered were not scored, but knowledge revealed there was taken into account where applicable to other prompts.

While the initial scoring of the CoRes was taking place, it became evident that some of the categories for the different levels were not well defined and the descriptors had to be refined so that the distinction between categories was more evident.

Since the refinement involved extensive changes to the rubric and I then had a better understanding of what the scoring entailed, I rescored all the CoRes. After the second scoring, the pre- and post-CoRes of four participants were scored by two experts for moderation. After this round of scoring the descriptors and the scores of the moderators and researcher were discussed until agreement was reached. Numeric category values were assigned for the different levels of competence: limited (1), basic (2), developing (3) and exemplary (4), to enable quantitative analysis of the outcomes. An inter-rater reliability coefficient for the scoring of the three coders was calculated. Since the data (the score each coder assigned to the responses to the CoRe prompts) is considered categorical and more than two coders did the scoring, the Fleiss' kappa was calculated

(Hallgren, 2012). A value of 0.68 was obtained, which indicates substantial agreement (Landis & Koch, 1977). One should bear in mind that although differences in scoring of one level indicate disagreement, these are not as dissimilar as differences of more than one level. The fact that this difference in level of agreement is not allowed for in the calculation of the inter-rater reliability coefficient can be seen as a limitation to the interpretation of this value. The main objective for this extensive process of discussion and refinement of the rubric is to be able to make reliable inferences from the data obtained from the CoRe and to present a rubric that can be used in a reliable way by other researchers in the field.

After the discussion between the three coders, certain descriptors in the rubric were refined again, which necessitated a third rescoring by the researcher. The scores obtained thus were fed into RUMM2030 for a Rasch analysis. (Comment: The RUMM2030 software automatically assigns scores of 0, 1, 2 and 3 to levels 1, 2, 3 and 4. It should thus be kept in mind that if, for example, in the RUMM analysis reference is made to say category 2, it actually refers to level 3).

5.3.2 Rasch analysis of the CoRe data

Although the CoRe tool was not initially designed for assessment and scoring of PCK, but rather as a tool to access a teacher's understanding of teaching the content (Loughran et al., 2004), researchers have adapted and used the tool as an instrument to capture and assess the TSPCK of teachers (Mavhunga et al., 2016; Qhobela et al., 2014; Rollnick et al., 2008). The section below describes how Rasch analysis was used to evaluate the validity of using the CoRe tool as a measurement of the TSPCK of the sample about teaching electromagnetism. As with the CK test, the following aspects were considered with the stacked data: overall fit to the Rasch model, response dependence, differential item functioning and unidimensionality and also category functioning, which comes into play when the scoring structure is not dichotomous.

Overall fit

The χ^2 probability value of 0.79 that was obtained indicates that the null hypothesis, that the items and the sample fit the Rasch model, can be accepted. Furthermore, the item-fit residuals (as explained in § 5.2.2) lie between -0.75 and 1.85, with a mean of 0.29 and SD 0.70 and the person-fit residuals between -1.37 and 1.31, with a mean of 0.12 and SD 0.58, indicating no misfitting items or persons.

Response dependence

No significant response dependence is indicated between any of the items (see Figure 5- 14) and one can assume that the items function independently. A negative correlation was flagged for items A4 and E1, meaning that students who scored high in the one scored low in the other. These items do not elicit knowledge about related constructs and there is no logical argument why such negative correlation should exist. If such a correlation should persist in other studies or in larger samples, it would require closer investigation.

Person-Item Residual Correlation Matrix

Principal Component Summary | PC Normalised Vectors | PC Loadings | Varimax Rotation Loadings | Res

Item	A0	A1	A2	A3	A4	B1	C1	D1	D2	E1
A0	1.000									
A1	-0.152	1.000								
A2	0.176	-0.155	1.000							
A3	-0.111	-0.211	-0.130	1.000						
A4	-0.028	-0.250	-0.222	-0.127	1.000					
B1	-0.260	0.033	-0.232	-0.293	-0.010	1.000				
C1	-0.136	-0.243	-0.089	-0.030	0.101	-0.267	1.000			
D1	-0.162	-0.051	-0.320	-0.117	0.127	0.186	-0.292	1.000		
D2	0.103	0.257	-0.213	-0.187	-0.284	-0.252	0.237	-0.287	1.000	
E1	-0.312	-0.044	0.177	0.256	-0.426	-0.185	-0.173	0.005	-0.219	1.000

Figure 5-14: Item correlation for pre-and-post-CoRe

Category functioning

This analysis determines whether the scoring categories are well defined and distinguish clearly between the knowledge levels of the respondents. RUMM provides category probability curves for each item with the probability of obtaining a value in a certain category against the person location. Figure 5-15 shows such a plot for an item (B1) for which the categories function adequately.

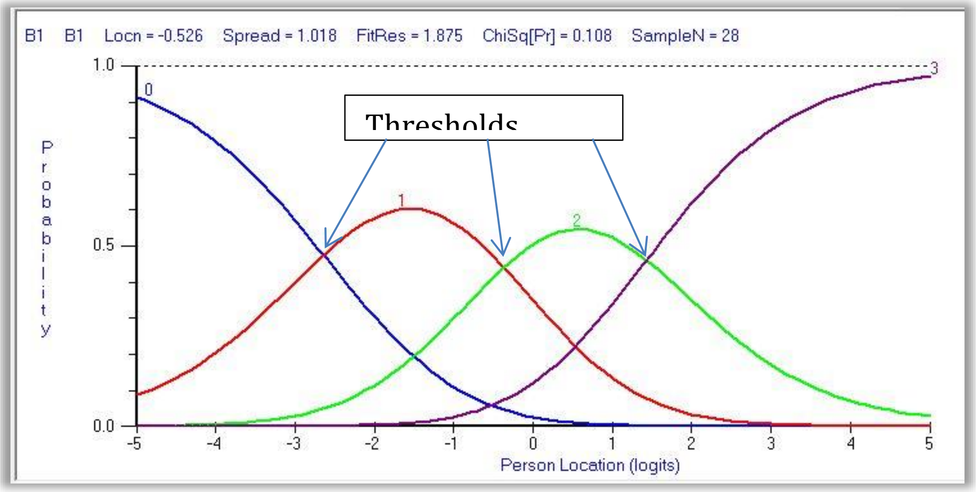


Figure 5-15: Category probability curve for item B1

It is clear from the graph that as the ability of a respondent (person location) increases, the probability of scoring at a higher level increases. The transition from one category to the next is known as a threshold. Information similar to that given by the category probability curve is given by a threshold map, but then for all items on one map (Figure 5-16).

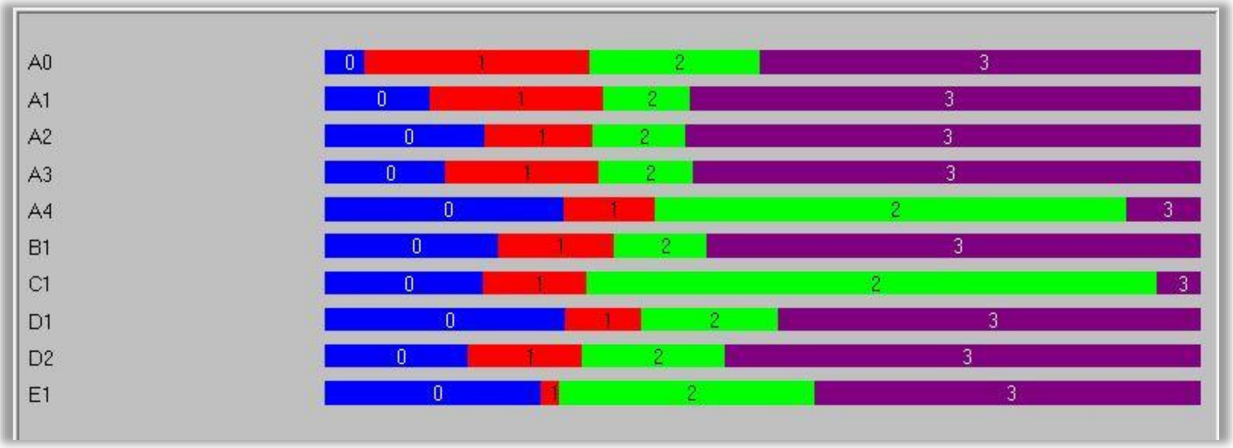


Figure 5-16: Threshold map for pre- and post-CoRes

When thresholds are disordered, it happens that a person with higher ability is more likely to get a lower score than a person with lower ability, which may be an indication that the descriptors of the categories do not adequately distinguish between levels of knowledge or competence. The threshold map will then flag the items for which that is the case. For the pre- and post-CoRes no items had disordered thresholds, but item E1 showed that the descriptors of category 1 (that is level 2 in the rubric) does not satisfactorily distinguish it from the neighbouring levels and the decision was made to revise them. An excerpt from the rubric is given in Table 5-3 (p.94), showing the descriptors for item E1 and the changes made in red. The requirement to provide explanatory notes was deleted from the descriptors of levels 2 and 3, since the prompt did not explicitly require such information. It was however, believed that such information would clearly distinguish a respondent with exemplary TSPCK from the rest.

Table 5-3: Excerpt from CoRe rubric

E. Representations and analogies				
	Limited (1)	**Basic (2)**	**Developing (3)**	**Exemplary (4)**
E1. What represen-tations 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.	- ~~Proper~~ The selection of representations (visual and/or symbolic) ~~without explanatory notes to make links to aspect(s) of concepts considered~~ is insufficient. - There is no evidence how the use of the representation will lead to increased understanding of concepts.	- ~~Proper~~ An adequate selection of representations (visual and/or symbolic) ~~without explanatory notes to make links to aspect(s) of concepts being explained~~ 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.

After the above-mentioned refinement of the rubric, item E1 in the pre- and post-CoRes was rescored. At this stage I was acutely aware that I could be biased when assigning new scores for the sake of obtaining a better threshold map for the item and the new descriptors were therefore rigorously applied. The new threshold map obtained after rescoring is shown in (Figure 5-17).

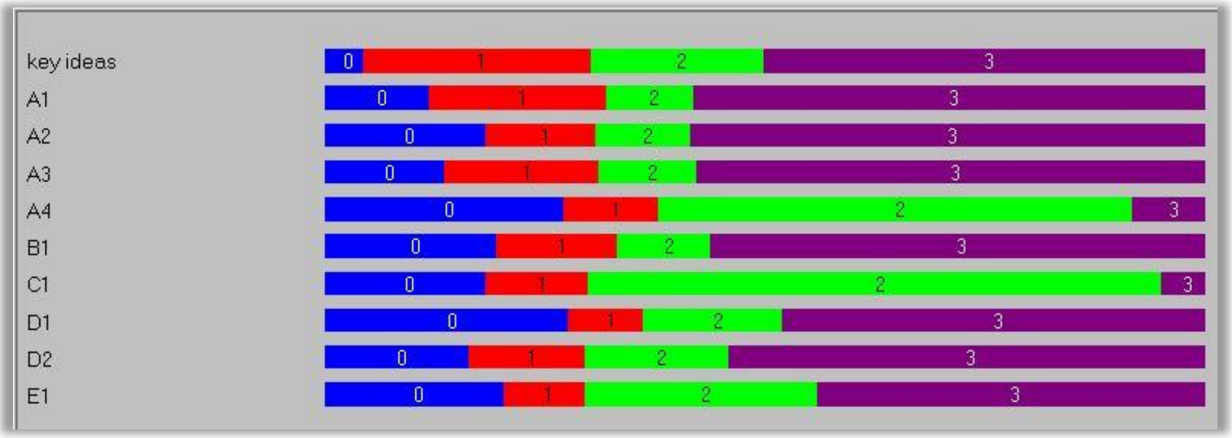


Figure 5-17: Threshold map for pre- and post-CoRes after rescoring item E1

Unidimensionality and differential item functioning

Because of the origin and design of the CoRe tool one can assume that it is unidimensional for measuring PCK for a specific topic. Furthermore, although CK has an important effect on PCK, a study by Kirschner, Borowski, Fischer, Gess-Newsome, and Von Aufschnaiter

(2016) demonstrated that CK and PCK, together with pedagogical knowledge (PK) can be regarded as separate dimensions of teacher knowledge. Another factor that can affect the measurement of TSPCK by means of the CoRe tool, is the primary language of the participants. As with the CK tests this could not be analysed, since there was only one English first language speaker in the group. Also, as with the CK-tests, a DIF analysis was done with gender as a person factor and none of the items was flagged for differential functioning.

With an overall fit analysis that indicates that the sample and the instruments fit the Rasch model, the result of the analysis can now be interpreted.

5.3.3 Comparison of the pre- and post-CoRes

As a reminder and for clarity, Table 5.4 shows how the different prompts in the CoRe tool relate to the five components of TSPCK (see § 2.4.1).

Table 5-4: Summary of the prompts in the CoRe tool and related TSPCK components

Component		Prompts	Clarification of the component in terms of TSPCK
(i)	Curricular saliency	A0	Selecting key ideas. Understanding which are the basic ideas that need to be conceptually developed to have a sound understanding of the topic and its sequencing.
		A1-A4	Knowledge of the important concepts that need to be taught for each key idea and its sequencing; this includes knowledge of what the pre-concepts of a particular key idea are and what the significance of the topic in the curriculum is.
(ii)	What is difficult to understand?	B1	Awareness of concepts that need dedicated attention and interventions when teaching the key idea.
(iii)	Learner prior knowledge	C1	Knowledge of learners' thinking about the concepts at hand. This includes knowledge of the typical alternative ideas, misconceptions, common errors and knowledge of the concepts learners normally understand correctly.
(iv)	Conceptual teaching strategies	D1, D2	The ability to design instruction strategies that keep in mind the difficulties and misconceptions learners have, knowing the representations to use and the questions to ask to support conceptual understanding of the key idea. This component requires integration and interaction of the other four components.
(v)	Representations	E1	Knowledge of demonstrations, analogies, diagrams, models and other material (e.g. simulations) and how to use these to support the conceptual development of the key idea.

The final raw scores of the 14 participants for the pre and post-CoRes are given in Table 5-5. (See appendices I and J for examples of CoRes completed by two participants.)

Table 5-5: Raw scores of pre- and post-CoRes

	Student	Pre-CoRe scores										Post-CoRe scores									
		A0	A1	A2	A3	A4	B1	C1	D1	D2	E1	A0	A1	A2	A3	A4	B1	C1	D1	D2	E1
1	AW	2	2	1	2	1	2	1	2	1	2	3	2	3	2	1	1	2	1	2	3
2	BM	2	2	1	2	1	2	2	1	2	1	2	2	2	3	1	1	3	1	2	2
3	HD	3	2	2	1	1	2	1	1	1	1	3	4	4	4	3	4	3	4	3	4
4	JD	2	2	2	1	2	2	2	2	2	1	3	3	4	3	3	2	3	2	3	2
5	DK	2	1	1	2	1	2	1	1	1	1	2	3	2	1	1	2	3	1	3	2
6	MS	2	1	1	2	2	1	2	1	1	1	4	3	4	3	2	3	3	2	3	3
7	VS	1	1	1	1	1	2	1	1	1	1	2	2	1	1	1	1	1	1	2	1
8	KM	2	2	2	2	1	3	1	1	2	2	3	2	1	3	2	2	3	2	3	2
9	HS	2	2	3	2	1	2	2	2	2	2	3	3	3	4	1	2	3	3	4	3
10	LM	2	1	2	2	1	1	1	1	1	1	3	2	3	2	2	1	2	1	3	2
11	MW	2	3	2	3	1	1	1	1	2	3	3	4	3	4	3	3	2	3	3	3
12	NL	2	2	2	2	3	3	2	2	2	2	2	2	1	2	2	1	3	1	2	1
13	TM	1	1	2	2	1	1	2	1	1	3	3	2	2	2	2	2	2	3	3	3
14	NB	2	3	2	2	2	3	2	3	2	2	2	4	3	3	2	4	3	2	4	3

Racking the pre- and post-CoRe scores for the Rasch analysis places the pre- and post-CoRe data along the same ruler and enables the researcher to track how the participants' performance in their responses to the CoRe-prompts change from pre- to post-intervention (Wright, 2003). Figure 5-18 shows the item map of the racked data for both CoRe assessments. The pre-CoRe and post-CoRe items are labelled with an A and a B

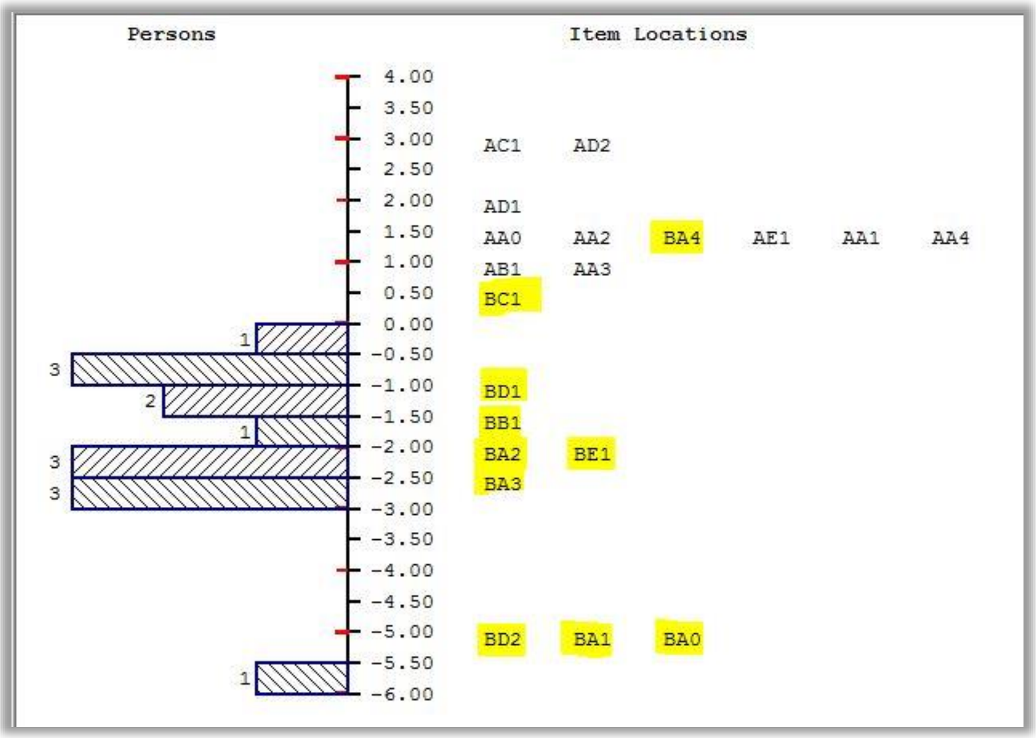


Figure 5-18: Item map for the pre-and post-CoRe with racked data

respectively before each prompt code. In Figure 5-18, the post-CoRe prompts are highlighted. The higher a person appears on the person-location side of the ruler, the higher the ability of the person compared to the instrument and the rest of the sample. The higher an item appears on the item location side of the ruler, the more difficult the item is perceived to be by the participants. A participant with average ability will have a less that 50% chance to obtain a high score in the items above the 0.00 item location. It is evident from the map that the participants did not perform well in any of the items (prompts) in the pre-CoRe. The prompts in the post-CoRe were regarded as less difficult and all the participants (but one) had a better chance to score higher in the post-CoRe. The participant with the lowest person location was student VS, who also scored lowest in the CK tests. His class attendance was very poor and he did not receive the full benefit of the intervention. Prompts A4 and C1 in the post-CoRe still proved challenging to elicit high scores, whereas A0, A1 and D2 were the prompts that showed the greatest improvement. Possible reasons for these observations are discussed in the next section.

Stacking the CoRe data places the participants before and after the intervention on the same ruler, comparing the group of participants with themselves. Stacking resulted in the person-frequency distribution (Figure 5-19) showing the number of participants at different person locations for both the pre-Core (in red) and the post-CoRe (in blue). The improvement from pre- to post-CoRe is significant with an ANOVA p-value of 0.0043.

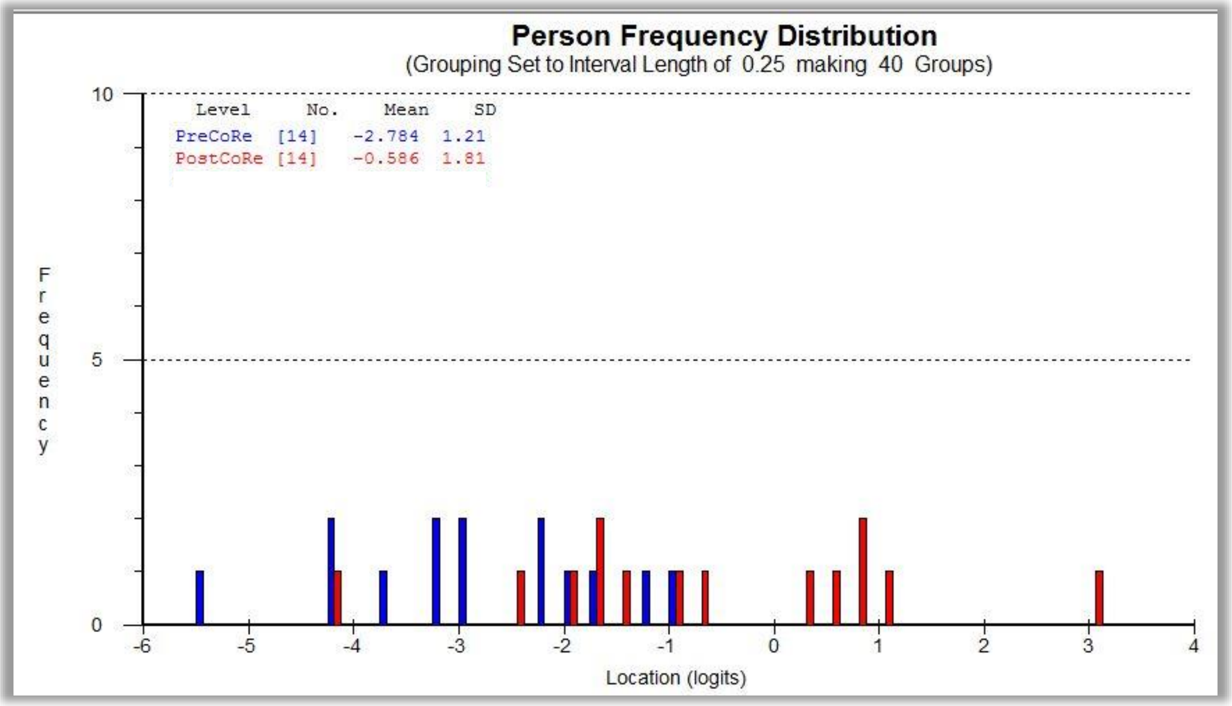


Figure 5-19: Person frequency distribution for the pre-CoRes (blue) and post-CoRes (red).

The graph in Figure 5-20 compares individual students' person locations (an indication of student performance) in the pre- and post-CoRes in order of decreasing performance in the pre-CoRe. The increase in the performance for all individuals (but one) is also evident in this graph. Student NL did not construct an improved CoRe after the intervention, although she showed above average improvement in her CK test. This seems irregular and her CoRes will be investigated qualitatively in the next section.

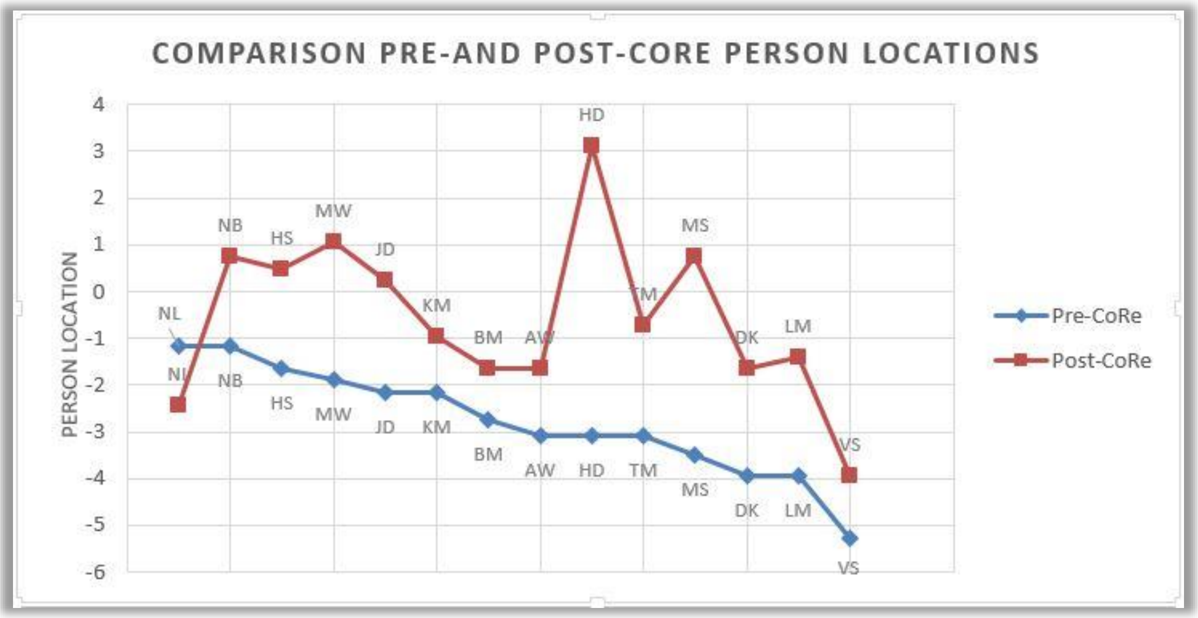


Figure 5-20: Comparison of individual performances in the pre- and post-CoRe

For a direct comparison between performance in the CK test and the CoRe, the corresponding person locations, being a measure of performance, were placed on the horizontal and vertical axes respectively in Figure 5-21. This comparison was deemed necessary since literature shows (Rollnick, 2017) that the development of CK is closely linked to the development of PCK about a topic.

In the graph on the left (Figure 5-21) it can be seen that most of the students had negative person locations for both the pre-CK test and CoRe. After the intervention, six students moved to the first quadrant with positive person locations in both the CK test and CoRes (grouped in red). This improvement in CK, indicating richer conceptual understanding of the topic and development of PCK during the intervention, supports the notion expressed by Mavhunga (2014) that CK is not necessarily a *precursor* to PCK. PCK about a topic can develop simultaneously when the student is stimulated to think about the content for the purpose of teaching it. Furthermore, five other students (grouped in blue) who improved in the CK test did not manage to reach positive person locations for the CoRe. This seems to support the evidence in the literature (Davidowitz & Potgieter, 2016) that although enhanced CK is a necessary component of good PCK about a topic, it is not sufficient. Knowing and understanding more about a topic does not automatically imply an increased ability to reason about the topic in terms of teaching. In addition, the fact that no students were placed in the top left quadrant after the intervention is an indication that for this sample, poor CK did not translate into good PCK.

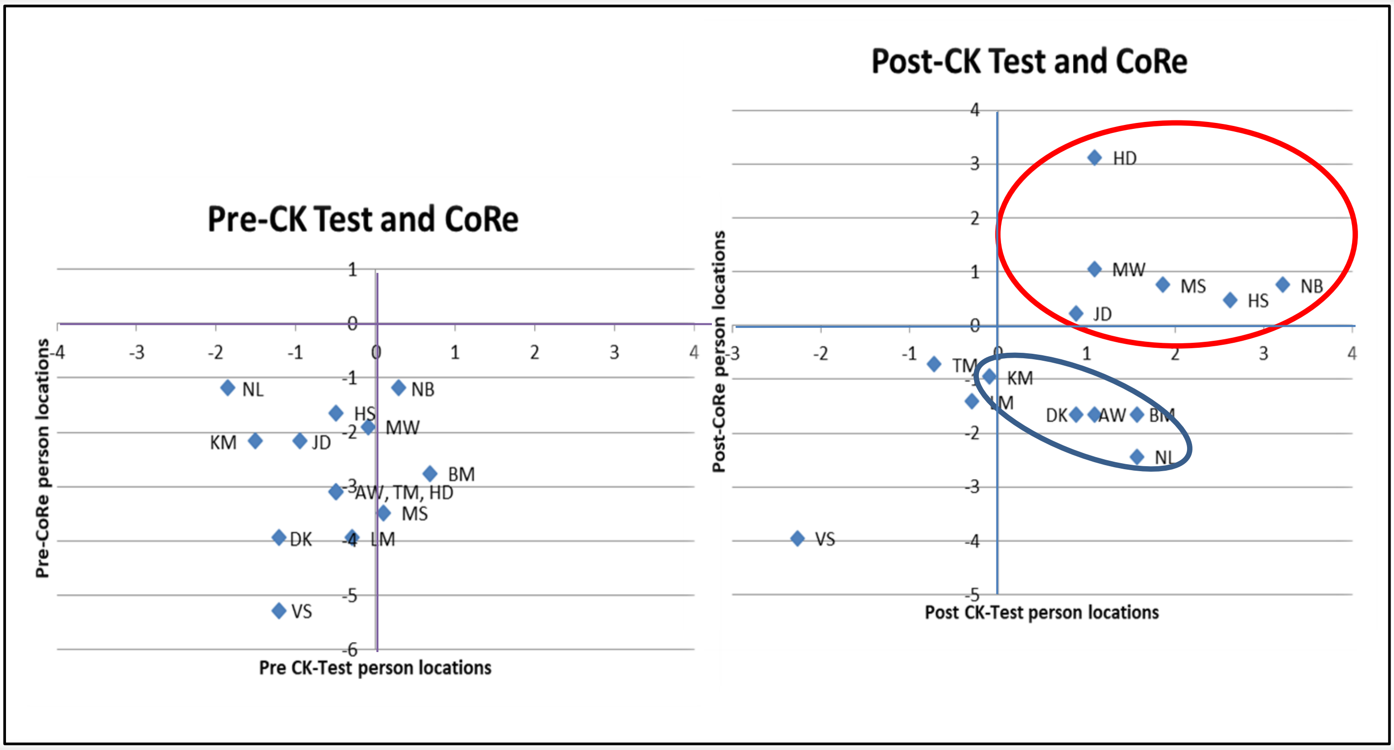


Figure 5-21: Scatterplots of performance in TSPCK (CoRes) vs performance in CK tests

5.3.4 Qualitative look at the pre- and post-CoRes

As seen in the discussion above, the Rasch analysis showed conclusively that the students in general had a better knowledge of the components of PCK about electromagnetism after the intervention. How each of these components was affected can be investigated through a qualitative analysis of the responses to the prompts in the CoRes. To support this analysis, it was necessary first to take a quantitative look at how the performance of the students changed over time for each prompt. For this information I used the Rasch analysis done with the racked data (Wright, 2003), taking the pre- and post-CoRe as separate tests placed along the same ruler, as for the data displayed in Figure 5-8 (p.82). The item locations for the pre- and post-CoRes are shown in Figure 5-22. To read this plot, one should keep in mind that the higher the item location, the more difficult it was for participants to attain a high score, and the lower the general score was for that item.

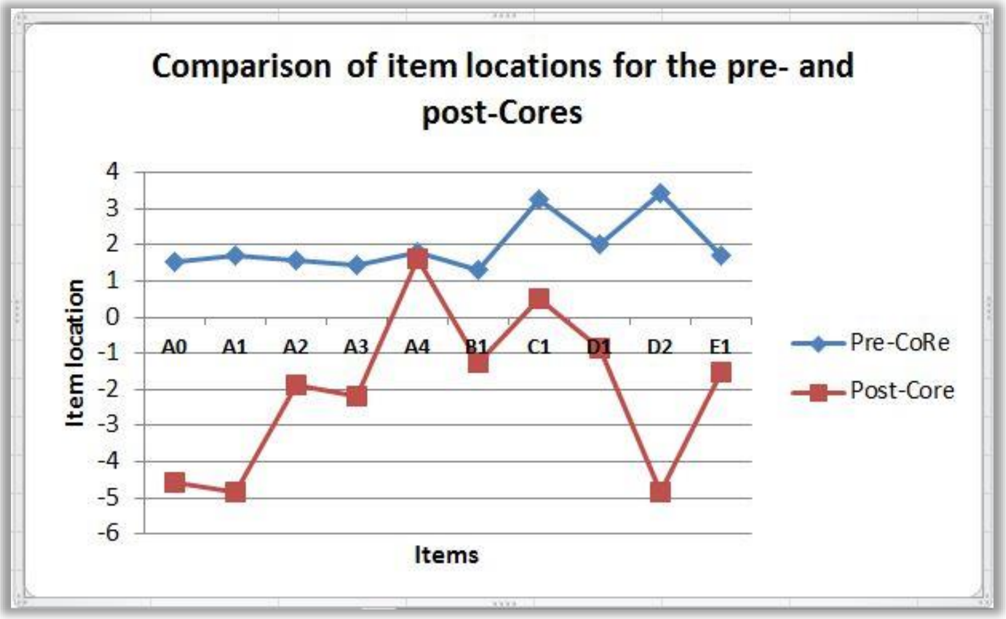


Figure 5-22: Comparison of pre-and post-CoRe item locations

As was concluded from Figure 5-8, one can clearly see that items A4 and C1 were prompts that the students still experienced as difficult after the intervention, whereas prompts A0, A1 and D2 elicited highly improved responses from the students. In the discussion that follows, qualitative evidence for these observations will be drawn from the students' CoRes. Each component of TSPCK and its corresponding prompts will be discussed separately.

(i) Curricular saliency (prompts A0 to A4)

Selection of key ideas was one aspect in which the students improved noticeably from the pre- to the post-CoRe. The key ideas suggested by the expert CoRe were:

- A magnetic field exists around a current-carrying conductor
- The basic principle of the phenomenon of induction
- Magnetic flux is the total magnetic field over an area perpendicular to the field
- Electromagnetic induction and Faraday's law.

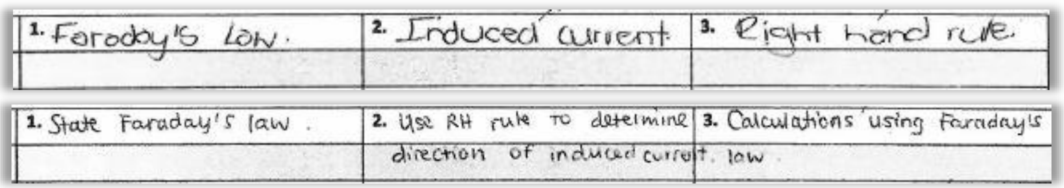
While the students did not formulate their key ideas as expressed above, they mainly selected ideas that were directly related to those in the expert CoRe with inclusion of a few others. The data in Table 5.6 shows how many students selected a particular key idea in each of the CoRes.

Table 5-6: Summary of the selection of key ideas

(Key ideas that are in line with the expert CoRe (Appendix H) are highlighted. It should be noted that the expert CoRe presented four key ideas, whereas students were requested to select three key ideas when they constructed their CoRes)

Key idea	Selected in pre-CoRe	Selected in post-Core
Magnetic field around a conductor	8	13
The phenomenon of induction (without referring to Faraday's law)	6	6
Magnetic flux	4	9
Faraday's law (electromagnetic induction)	11	6
Right-hand rule	7	5
Magnetic field of a magnet	2	0
Force experienced in a magnetic field	1	0
Key ideas related to electric fields	3	0

It was interesting that seven students decided to choose the "*right-hand rule*" as a key idea in the pre-CoRe and five in the post-CoRe. See examples in Figure 5.23 below. The right-hand rule is not a scientific concept but a rule of thumb to assist the science student



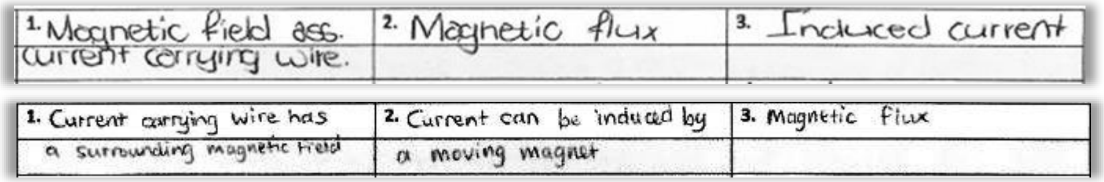
1. Faraday's law.	2. Induced current	3. Right hand rule.

1. State Faraday's law.	2. Use RH rule to determine direction of induced current.	3. Calculations using Faraday's law.

Figure 5-23: Student JD (top) and student MS (bottom): Prompt A0, pre-CoRe

in determining directions of current and magnetic field; however, the students perceived this as a scientific key idea. The students confused the skill to complete a procedure or calculation successfully with conceptually understanding the idea and therefore saw such a skill as a key concept. This can also be seen in the pre-CoRe of student MS selecting "*calculations using Faraday's law*" as a key idea (Figure 5-23). The students' ability to choose appropriate key ideas improved after the intervention. See examples in Figure 5-24 of the same two students as in Figure 5-23.

Five more students selected magnetic flux as a key idea after the discussion of the importance of this concept during theme 6 in the intervention (see § 4.2.6). Student JD

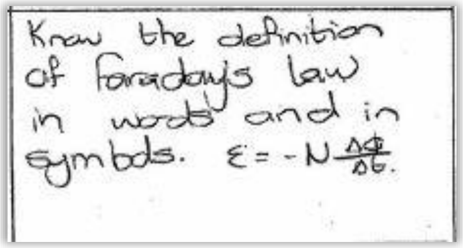


1. Magnetic field ass. current carrying wire.	2. Magnetic flux	3. Induced current

1. Current carrying wire has a surrounding magnetic field	2. Current can be induced by a moving magnet	3. Magnetic flux

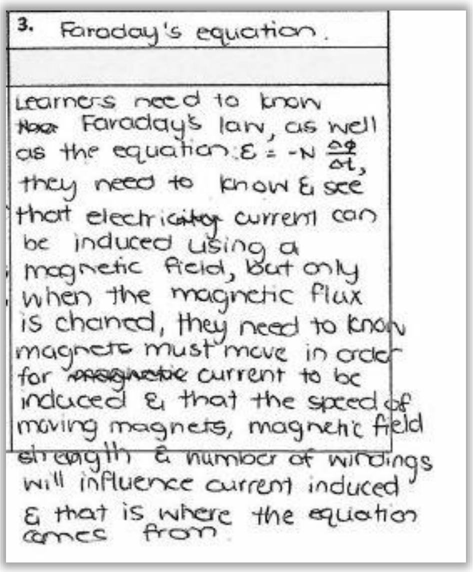
Figure 5-24: Student JD (top) and student MS (bottom), prompt A0, post-CoRe

indicated that magnetic flux should be taught before the concept of induced current. She saw magnetic flux as a pre-concept to the explanation and understanding of electromagnetic induction. Student MS, however, proposed first to present the phenomenon of inducing a current by moving a magnet in a coil (without mentioning Faraday's law) and then to introduce the idea of magnetic flux as a concept that supports the explanation of the induction. In both cases development of understanding of important concepts and their sequencing is evident.



Know the definition of Faradays law in words and in symbols. $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$.

*5-25a: Student AW's (**pre**-coRe)*



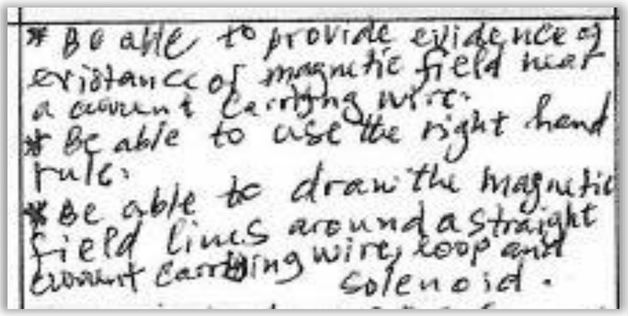
3. Faraday's equation.

Learners need to know Faraday's law, as well as the equation $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$, they need to know & see that electricity current can be induced using a magnetic field, but only when the magnetic flux is chaned, they need to know magnets must move in order for magnetic current to be induced & that the speed of moving magnets, magnetic field strength & number of windings will influence current induced & that is where the equation comes from

Figure 5-25: Responses to prompt A1   *5-25b: Student MW's (**post**-CoRe)*

The 11 students who selected Faraday's law as a key idea in the pre-CoRe supported their choice with a reference in prompt A1 to the equation and the symbols used in the equation, whereas students who used this idea in the post-CoRe in addition referred to subordinate ideas germane to the conceptual understanding of electromagnetic induction. Compare, for example, student AW's response in the pre-CoRe and student MW's in the post-CoRe in Figure 5-25. Responding to prompt A1 satisfactorily required adequate CK; as such, the poor CK of the students when writing the pre-CoRe, resulted in poor responses.

Student DK, for example, merely copied his response from the curriculum document in his pre-CoRe (Figure. 5-26, left) for the key idea: *magnetic field around a current-carrying wire*. In his post-Core (Figure 5-26, right) he revealed that he had an improved understanding of the important ideas that had to be conveyed to learners when teaching the topic. He understood the importance of giving evidence of the magnetic field by using compasses.


* Be able to provide evidence of existance of magnetic field near a current carrying wire.
* Be able to use the right hand rule.
* Be able to draw the magnetic field lines around a straight current carrying wire, loop and solenoid.

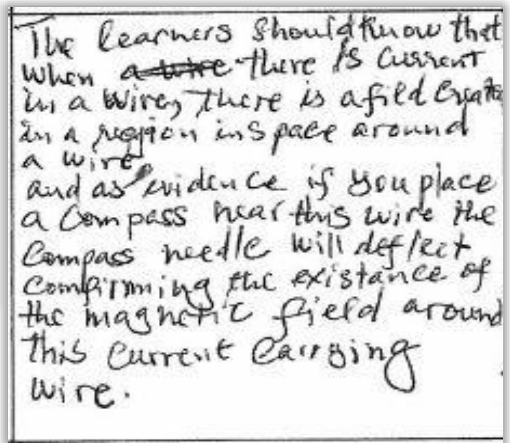
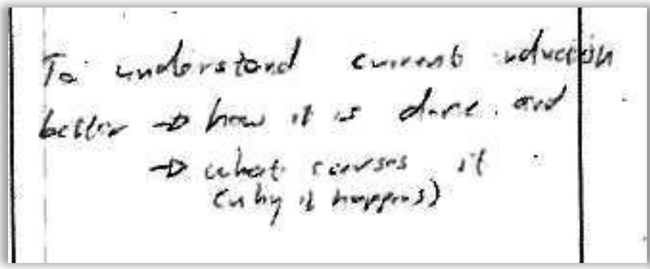
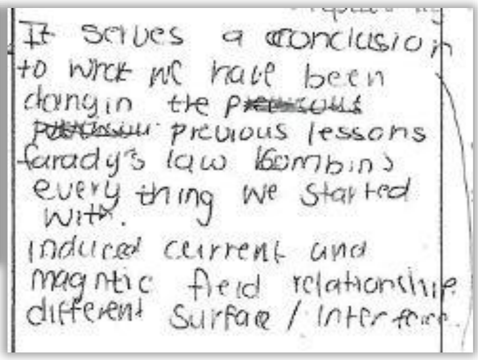

The learners should know that when a wire there is current in a wire, there is a field created in a region in space around a wire and as evidence if you place a compass near this wire the compass needle will deflect comfirming the existance of the magnetic field around this current carrying wire.

Figure 5-26: Student DK's response to prompt A1 (left: pre-CoRe, right: post-CoRe).

When responding to prompt A2, "Why is it important for learners to know this idea?", students often repeated the key idea as if they believed that there was no better reason


To understand current induction better → how it is done. and
→ what causes it (why it happens)

5-27a: Student BM key idea: induced current


It serves a conclusion to what we have been doing in the previous lessons faraday's law combins every thing we started with.
induced current and magntic field relationship different surface / interface.

5-27b: Student KM key idea: Faraday's law

Figure 5-27: Responses to A2 (pre-CoRe)

for learning the key idea than merely knowing it or as a culmination of what had been learned, as can be seen in the two examples in Figure 5-27.

Knowledge of scaffolding towards new concepts and sequential development as referred to in the rubric emerged in the post-CoRe of some students (Figure 5-28).

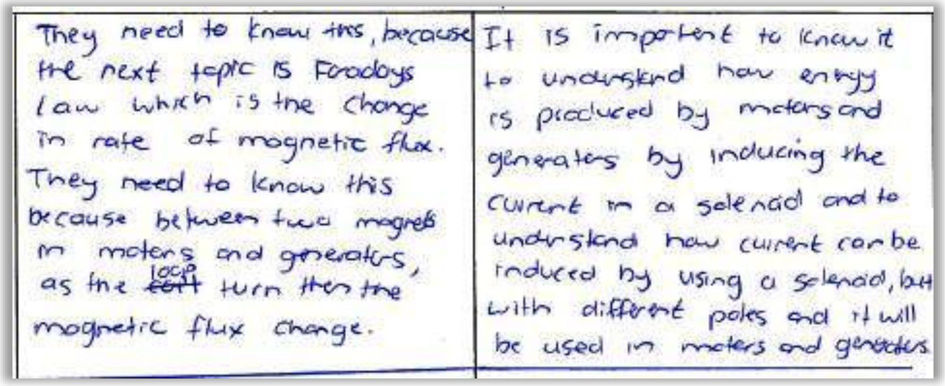

They need to know this, because the next topic is Faradays law which is the change in rate of magnetic flux. They need to know this because between two magnets in motors and generators, as the ~~[illegible]~~ loop turn then the magnetic flux change.	It is important to know it to understand how entrgy is produced by motors and generators by inducing the current in a solenoid and to understand how current can be induced by using a solenoid, but with different poles and it will be used in motors and generators

Figure 5-28 Student HD's response to A2 (post-CoRe); key ideas: magnetic flux and Faraday's law

In prompt A3 the CoRe tool required the participants to have knowledge about the pre-concepts that should be in place before an attempt is made to teach the new key idea. On average, the score improved in the post-CoRe as seen in Figure 5-22 (p.100), yet even though many students gave different responses in the post-CoRe they were of the same level as in the pre-CoRe. See for example student LM's responses (Figure 5-29), where he indicated his understanding of the concepts that should be in place before teaching *induced current*. In both CoRes his responses were scored as basic (level 2), because in both cases he selected relevant pre-concepts but omitted other very important ideas that should be in place. In the pre-CoRe he could have added magnetic flux and in the post-CoRe he could have mentioned that learners needed to know that whenever a current is induced in the solenoid an accompanying magnetic field is produced as well.

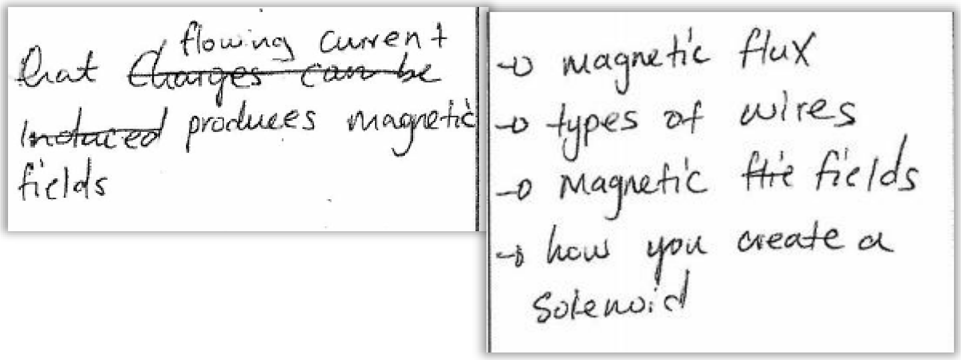
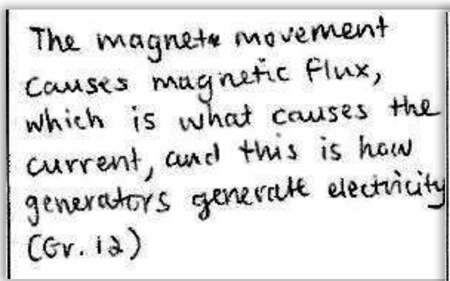
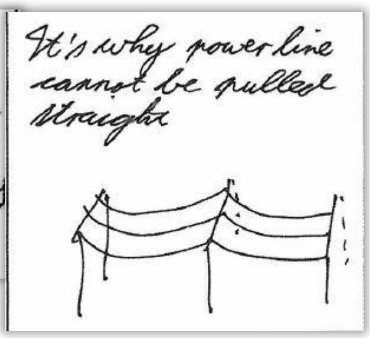
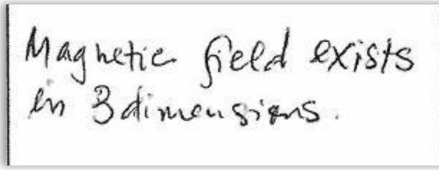
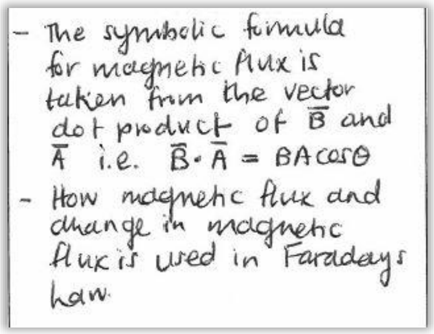

that ~~charges can be induced~~ flowing current produces magnetic fields	-> magnetic flux -> types of wires -> Magnetic ~~the~~ fields -> how you create a solenoid

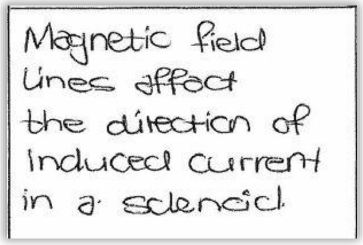
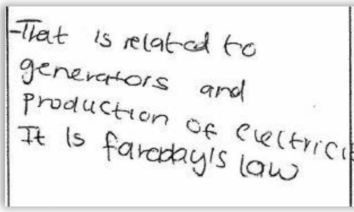
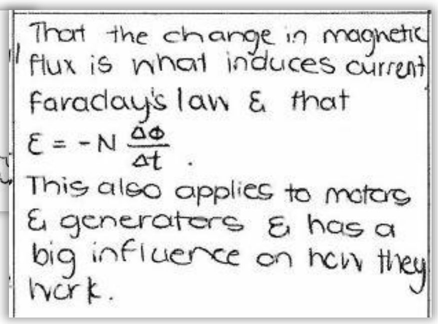
Figure 5-29: Student LM's responses to A3 in the pre- and post-CoRes

As can be seen in the graph in Figure 5-22, the students found it challenging to respond satisfactorily to prompt A4; "What else do you know about this idea that you don't intend learners to know yet?" even after the intervention. The importance of this prompt is that it elicits students' understanding of which concepts form foundations of key ideas that are addressed later in the curriculum. Seven students in the pre-CoRe and six students in the post-CoRe omitted responses to A4 for at least one of the key ideas. Other typical responses for A4 are shown in Table 5-7.

It is noteworthy that not all the responses to the prompts related to curricular saliency (A0 to A4) improved to the same degree after the intervention. A possible explanation is that A0 and A1 draw from a teacher's knowledge about the content, whereas prompts A2, A3 and A4 draw to a greater extent from a teacher's knowledge base gained by experience.

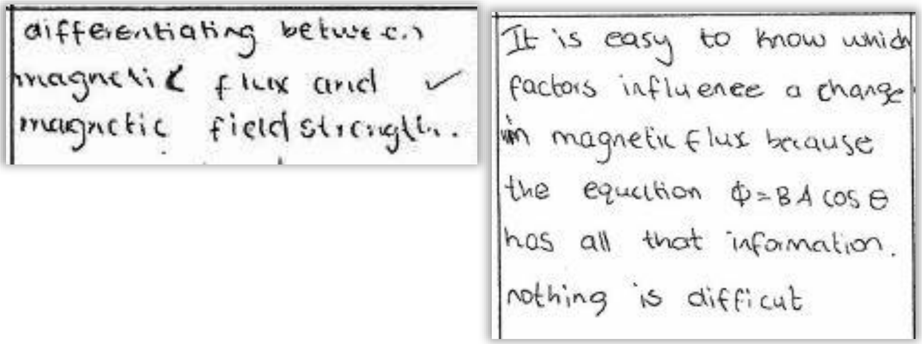
Table 5-7: Responses to prompt A4 in the post-CoRes

Typical response	Examples from the post-CoRe
1. Poor conceptual understanding Student MS does not reveal any understanding that current is induced as a result of *change* in magnetic flux. Student HS thinks the magnetic field around the power lines is the reason why they sag.	 The magnets movement causes magnetic flux, which is what causes the current, and this is how generators generate electricity (Gr. 12)  It's why power line cannot be pulled straight
2. Including concept fundamental to the key idea. Student DK gave this response to A4 for the key idea: magnetic field around a current-carrying conductor.	 Magnetic field exists in 3 dimensions.
3. Including concepts not relevant at school level Student NB includes the dot product, which is not studied in mathematics at FET level in the South African curriculum.	 - The symbolic formula for magnetic flux is taken from the vector dot product of $\vec{B}$ and $\vec{A}$ i.e. $\vec{B} \cdot \vec{A} = BA\cos\theta$ - How magnetic flux and change in magnetic flux is used in Faradays law.

Typical response	Examples from the post-CoRe
4. Poorly formulated Student JD did not formulate properly what the link between magnetic field and induced current is.	 Magnetic field lines affect the direction of induced current in a solenoid.
5. Improved responses Student KM's response in respect of the electromagnetic induction key idea and student MW's in respect of the magnetic flux key idea, showed improved understanding of the scaffolding of topics in the curriculum.	 That is related to generators and production of electricity. It is faraday's law  That the change in magnetic flux is what induces current Faraday's law & that $\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}$. This also applies to motors & generators & has a big influence on how they work.

(ii) What is difficult to understand? (Prompt B1)

Five students improved in this component after the intervention, but the other nine were scored the same or lower for their post-CoRe responses. A typical example of a weaker response to B1 was that of student NL, whose overall performance for the post-CoRe brought about a lower score. Figure 5-30 shows her pre- and post-CoRe responses in respect of the magnetic flux key idea.


differentiating between magnetic flux and magnetic field strength.

It is easy to know which factors influence a change in magnetic flux because the equation $\Phi = BA\cos\theta$ has all that information. nothing is difficult

Figure 5-30: Student NL's responses to prompt B1 in the pre-and post-Core.

In her pre-CoRe she presented a valid learner difficulty, stating that it is challenging to understand the difference between magnetic field and magnetic flux. In the post-Core, however, she remarked, referring to the same key idea, that nothing is difficult. This student's actual gain in the CK tests was 62%, which indicates that she had an apparently improved conceptual understanding of the content and did not find it difficult anymore to distinguish between magnetic flux and magnetic field. In her responses to this prompt she evidently drew from her own perception about the concept and was not thinking in terms of the her teaching of the idea and that this component was not part of her knowledge base as a teacher yet.

The participants did not have experience in teaching the concepts related to electromagnetism. Therefore, similar to student NL, they probably responded to this prompt by anticipating what would be difficult to teach drawing from their own experience as learners of the topic. The responses of student TM, being a left-handed person, and student LM, coming from an under-resourced school (Figure 5-31), are other examples of this trend.

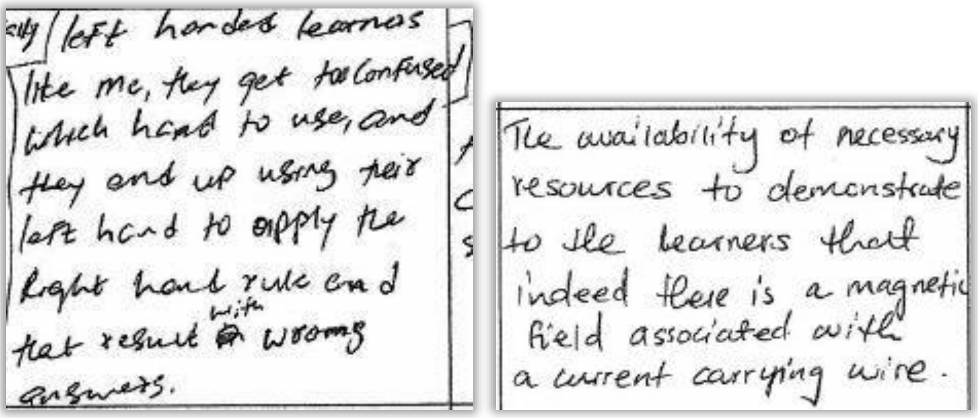
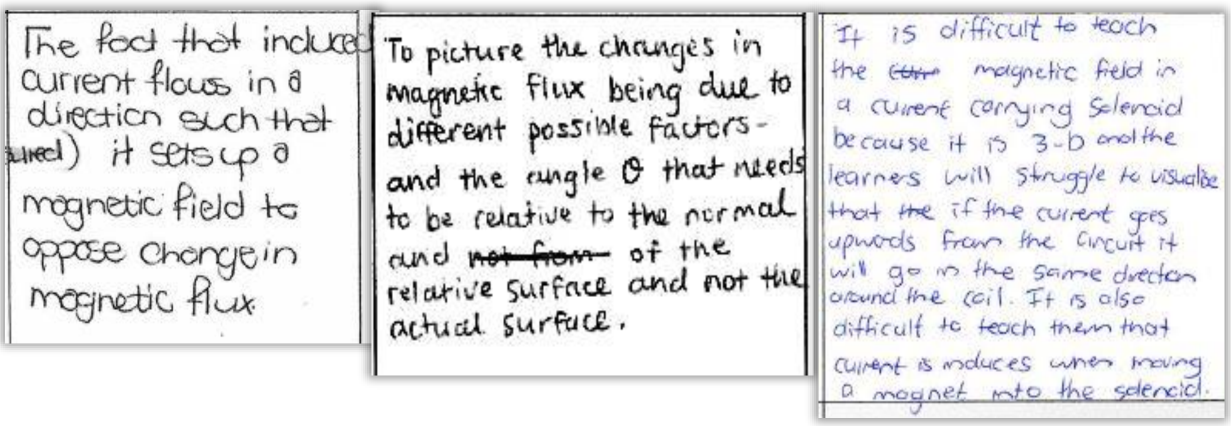


Figure 5-31: Students TM and LM's responses to B1 in the post-CoRe

Acceptable responses to prompt B1 included references to:

- finding the direction of the induced current by understanding that the magnetic field of the current will oppose the change in magnetic flux;
- finding the correct angle θ to substitute in the formula $\phi = ABcos\theta$ for calculating magnetic flux; and
- realising the three-dimensional nature of magnetic fields.

Knowledge of these three difficulties are evident in the examples in Figure 5-32 (p. 108).


The fact that induced current flows in a direction such that ...ced) it sets up a magnetic field to oppose change in magnetic flux

To picture the changes in magnetic flux being due to different possible factors - and the angle θ that needs to be relative to the normal and ~~not from~~ of the relative surface and not the actual surface.

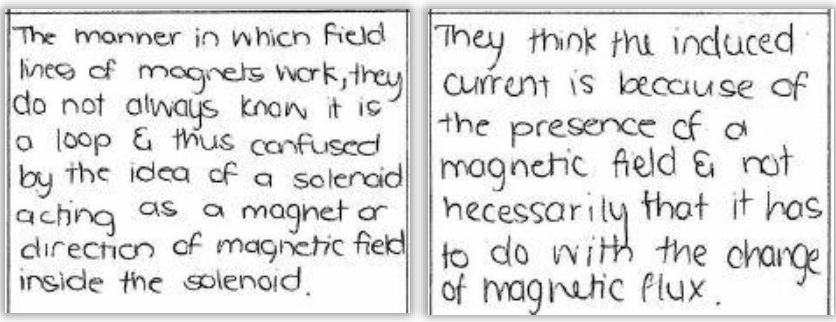
It is difficult to teach the ~~curr~~ magnetic field in a current carrying solenoid because it is 3-D and the learners will struggle to visualise that ~~the~~ if the current goes upwards from the circuit it will go in the same direction around the coil. It is also difficult to teach them that current is induces when moving a magnet into the solenoid.

Figure 5-32: Reponses to prompt B1 of students JD, MS and HD (post-CoRe)

(iii) Learner prior knowledge (Prompt C1)

Although this prompt only asked about misconceptions, mention of other typical alternative ideas and common mistakes that are encountered when teaching a particular key idea, was also accepted when scoring the responses. Giving evidence of exemplary knowledge about this component required the student to identify and describe a number of well-known documented misconceptions or other alternative ideas that learners may have (see the rubric in Appendix G and the expert CoRe in Appendix H). Because none of the students revealed such a level of competence, no one scored on level four for this component, although 12 of the students gave improved responses.

Markedly enhanced competence was evident in the responses of students MW and DK who could not identify even one misconception for any of the key ideas in their pre-CoRes. In her post-CoRe student MW referred to the problem learners have of realising that inside a solenoid the magnetic field's direction is from south to north. She noted too that learners do not understand that the magnetic flux through a coil has to change to induce current (Figure 5-33), which is a well-documented misconception that was assessed in the CK test.


The manner in which field lines of magnets work, they do not always know it is a loop & thus confused by the idea of a solenoid acting as a magnet or direction of magnetic field inside the solenoid.

They think the induced current is because of the presence of a magnetic field & not necessarily that it has to do with the change of magnetic flux.

Figure 5-33: Student MW's responses to C1 (post-CoRe)

In his post-CoRe (Figure 5-34), student DK realised the error in thinking about magnetic field lines *moving* from north to south, which many of his peers actually did in their CoRes (see the discussion in §5.3.5). He mentioned that a typical misconception was that learners think that a magnetic field moves from one place to another and its motion is indicated by magnetic field lines. However, he did not proceed to indicate that this misconception might lead to a misunderstanding of what magnetic flux is.

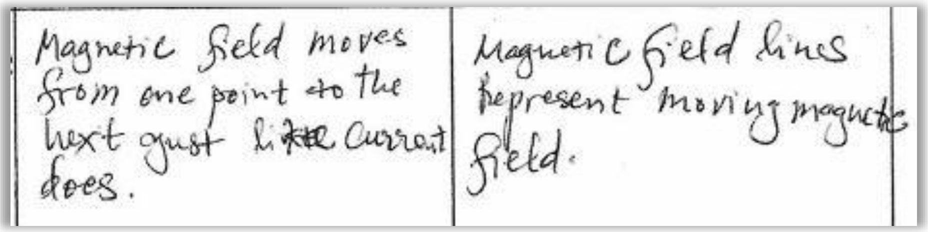
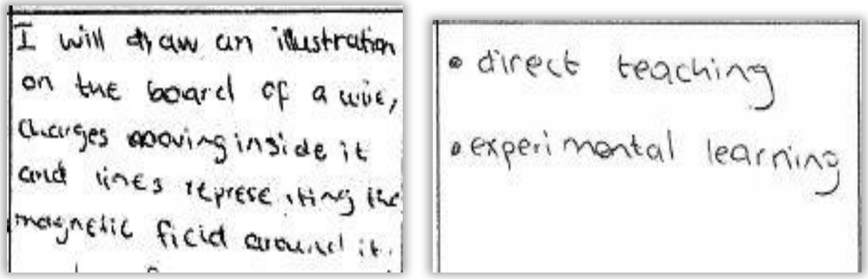


Figure 5-34: Student DK's responses to C1 (post-CoRe)

Figure 5-18 shows that this prompt elicited very low scores in the pre-CoRe and despite the improved responses of some students, they perceived this item as still the second most challenging item in the post-CoRe. A possible reason is that knowledge of learners' thinking and misconceptions is largely attained during teaching experience, which at the time of completion of the post-CoRes the participants did not have. Another reason is that these students themselves had misconceptions about the topic as revealed during the CK tests and that they alluded to in their interviews (discussed in Chapter 6).

(iv) Conceptual teaching strategies (Prompt D1 and D2)

One of the features of the students' responses to D1 is their mention of general teaching approaches, such as direct teaching, questioning, experimenting or other activities, without reference to the key idea and its conceptual development (compare with the discussion in §4.2.3 p.59). This emerged in five responses in the pre-CoRe and also five (not always the same five) in the post-CoRe. For student NL, who did not improve overall in the post-CoRe, this was one of the components where she demonstrated a decline in her ability to articulate her knowledge. Figure 5-35 shows a comparison of her pre- and post-CoRe responses for the key idea: *magnetic field around a current-carrying conductor.*



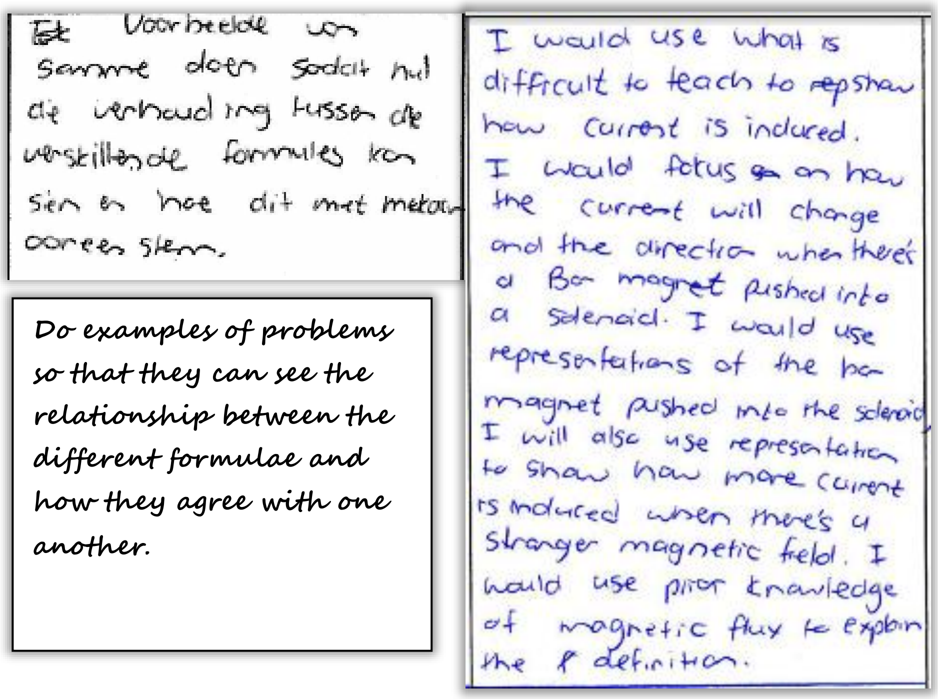
I will draw an illustration on the board of a wire, charges moving inside it and lines representing the magnetic field around it.

• direct teaching

• experimental learning

Figure 5-36: Student NL's responses to D1 (pre-and post-CoRe)

A main feature of this component is that it requires creative integration and interaction of the other four components. Six students showed improved responses to prompt D1, in which they revealed increased knowledge about representations, misconceptions and questioning and how to integrate these to achieve conceptual development of the key and subordinate ideas. Student HD's responses improved from limited to exemplary in this prompt for the key idea *Faraday's law* (see Figure 5-36).



Ek Voorbeelde van Samme doen sodat hul die verhouding tussen die verskillende formules kan sien en hoe dit met mekaar ooreen stem.

Do examples of problems so that they can see the relationship between the different formulae and how they agree with one another.

I would use what is difficult to teach to show how current is induced. I would focus on how the current will change and the direction when there's a bar magnet pushed into a solenoid. I would use representations of the bar magnet pushed into the solenoid. I will also use representation to show how more current is induced when there's a stronger magnetic field. I would use prior knowledge of magnetic flux to explain the definition.

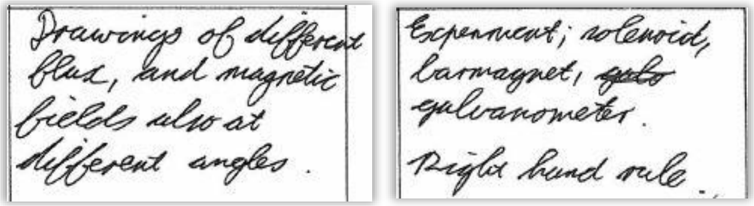
Figure 5-35: Student HD's response to D1; pre- and post-CoRe

Her pre-CoRe was presented in her first language, Afrikaans, and a translation of her response is given. In her pre-CoRe she referred to the solving of example problems so that learners can become familiar with the formulae. In the post-CoRe she mentioned how she would integrate other components to support conceptual development. The intervention was in English, which may account for the confidence with which she responded in English in her post-CoRe.

Twelve students gave improved responses to prompt D2. During the intervention, especially when theme 5 was discussed, focussed attention was paid to the questions that should be asked and how they could be sequenced while doing demonstrations and simulations. This may have resulted in the remarkably improved responses to prompt D2.

(v) Representations (Prompt E1)

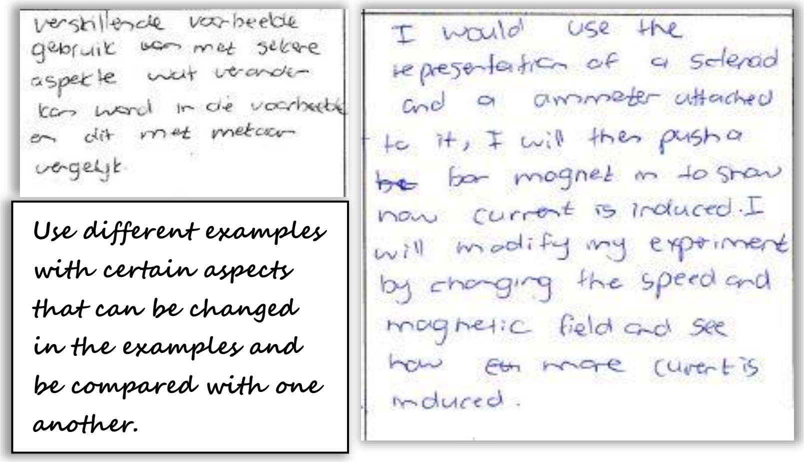
In the pre-CoRes the students' responses to prompt E1 revealed that they lacked knowledge about representations, analogies and diagrams that could be used to support the teaching of electromagnetism, with seven students being placed in the category of limited knowledge (level 1). The improvement in the post-CoRe was apparent, with only two students still in the limited category. Figure 5-37 shows the responses of student HS in the pre- and post-Core for the key idea: *Faraday's law*. It seems that in the pre-CoRe he was not aware of anything, other than drawings, to support the transformation of knowledge about electromagnetic induction. In the post-CoRe he revealed knowledge of the value of practical demonstrations in teaching this concept for understanding.


Drawings of different flux, and magnetic fields also at different angles.

Experiment; solenoid, barmagnet, ~~galv~~ galvanometer. Right hand rule

Figure 5-37: Student HS's responses to E1; pre- and post-CoRe

Another typical example (Figure 5-38) of improved knowledge about representations, from level 1 to level 4, was student HD again. As before the translation of her pre-CoRe response is given below.


verskillende voorbeelde gebruik van met sekere aspekte wat verander kan word in die voorbeelde en dit met mekaar vergelyk

Use different examples with certain aspects that can be changed in the examples and be compared with one another.

I would use the representation of a solenoid and a ammeter attached to it, I will then push a ~~be~~ bar magnet in to show how current is induced. I will modify my experiment by changing the speed and magnetic field and see how ~~en~~ more current is induced.

Figure 5-38: Student HD's response to E1; pre- and post-CoRe

Student NB, who did not attend the session when representations (theme 5) were discussed, did not realise what the word *representations* means in the context of the CoRes. She thought that it referred to something that represented reality, hence her singular response to E1 (Figure 5-39).

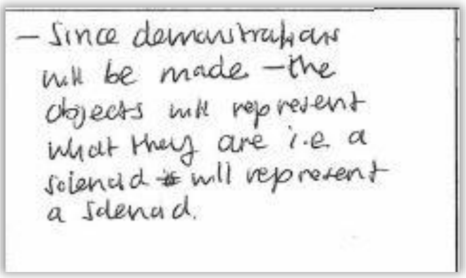


Figure 5-39: Student NB's response to E1 (post-CoRe)

The excerpts above, of responses in the CoRe tool for the five components of TSPCK, are unique examples that support the quantitative result indicating a significant improvement in students' knowledge about teaching electromagnetism. However, in some instances it was difficult to determine what the level of knowledge of a participant was, because the meaning of responses was obscured by students' lack of proficiency in English. Examples of these are presented in the next section.

5.3.5 Emerging issues

Students sometimes used inappropriate prepositions and verbs that cast doubt on their own understanding of the content and if used in teaching may eventually lead to incorrect understanding by the learners. A common example of the use of a wrong verb was when students associated the verbs *flow* or *move* with a magnetic field and magnetic field lines (Figure 5-40). These statements may lead to the perception that the "flow" or "motion" of the magnetic field is in fact the change in magnetic flux that is required for electromagnetic induction.

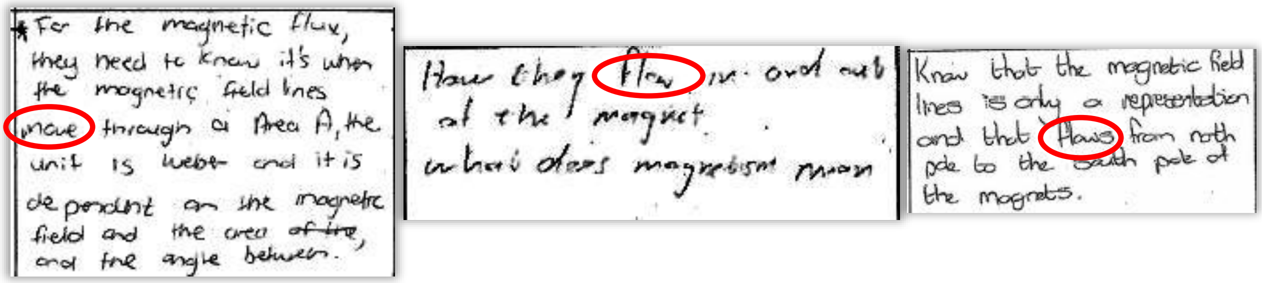


Figure 5-40: Responses of students HD, BM and AW for A1 in the pre-CoRe

Another example where lack of vocabulary could have been the reason for the poor formulation of responses is the response of student KM (Figure 5-41). In her response to A3 she probably intended to refer to direct and alternating current when she used the words normal and induced current. In the other example, which was her response to A4, it is not evident whether she really thought that the magnetic field was inside the current-carrying wire or whether it was merely the use of the wrong of preposition that gave this impression.

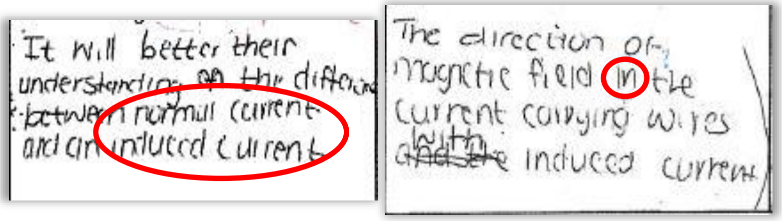


Figure 5-41: Reponses of student KM to A2 and A4 in the pre-CoRe

Student AW's primary language is Afrikaans and his lack of proficiency in English is evident in the formulation of his responses (Figure 5-42). For prompt A3 in his post-CoRe, he wrote a sentence that seemingly made no sense and may point to a lack of conceptual knowledge.

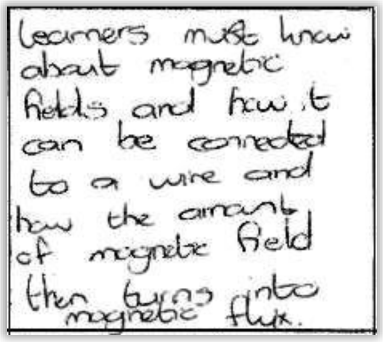


Figure 5-42: Student AW's response to A3 (post-Core)

Understanding his first language, however, I was able to recognise that what he probably meant was: learners must know what the connection (link) is between [current-carrying] wires and magnetic fields and how the concept of magnetic field is used to explain magnetic flux.

5.4 Summary

In Chapter 5, I compared the quantitative outcomes of the CK tests and the pre- and post-CoRes and showed that that there was a significant improvement in both these assessments after the intervention. It was indicated in the chapter that the sample and both the CK test and the CoRe tool fit the Rasch model and that a Rasch analysis could be used to explore the outcomes of the CK tests and the CoRes.

Very low CK was evident at the start of the intervention and it became clear that for this sample, the level of undergraduate Physics of a participant was no predictor of performance in the CK tests; neither was the outcome in the pre-test a predictor of the outcome of the post-test. The average in the CK test improved from 37% (SD 13.1%) in the pre-test to 65% (SD 23.5%) in the post-test. The difference in SD's indicated that there was a larger separation between the low and high performers in the post-test than in the pre-test, which can be seen as one of the effects of the intervention.

Although the focus of the intervention was not on teaching electromagnetism content explicitly, a qualitative look at the items in the CK tests indicated that the discussion about representations for teaching electromagnetism had a pronounced effect on the performance in certain items of the test. For example, item 1.2 could be linked directly to the demonstration of the magnetic field around a current-carrying conductor and slide three in the PowerPoint presentation that was used during the intervention (see §4.2.5).

Thirteen of the 14 students constructed improved CoRes after the intervention. The one student who did not improve was an interesting case and deserved further attention. She was one of the students whose lessons were observed and who was interviewed during teaching practice. The outcome of this investigation will be discussed in the following chapter.

Although the students showed enriched competence when responding to the CoRe prompts after the intervention, prompts A4 and C1 did not elicit much improved responses. A qualitative analysis of the responses suggested that these two prompts draws from a knowledge base gained from experience rather than the intervention.

The results gained from the quantitative and qualitative analysis of the CK tests and CoRes, will be used in Chapter 7 to answer the first research question:

- What is the impact of an intervention, focussing on the components of TSPCK, on the level of CK and PCK of pre-service teachers in electromagnetism?

The second research question enquires about the ability of students to enact their learned PCK in teaching situations. Three students were followed into the schools during teaching practice and their lessons were observed and video-recorded for evidence of the manifestation of PCK about electromagnetism. The outcome of this investigation is reported in Chapter 6.

Chapter 6

Topic-specific PCK enacted during teaching practice:
Lesson observations and interviews

In this chapter, I report and elaborate on my search for evidence that pre-service teachers can translate aspects of teacher knowledge attained during their training in their first formal teaching experiences. The data sources and analysis from which this evidence emerges are discussed in this chapter and comprise video material of the lessons on electromagnetism that the participating students presented and semi-structured and video stimulated recall (VSR) interviews conducted with the participants after formally teaching electromagnetism to Gr 11 classes.

6.1 Introduction

After the intervention (discussed in Chapter 4) that had taken place during the first seven weeks of their final year the students were placed at schools for teaching practice. Fourth-year students have to complete their teaching practice in two modules, each stretching over approximately ten weeks; from April to June (second school term) and from July to September (third school term) respectively. Students can choose which of their electives (major subjects) they want to teach in each of these modules. Seven of the 14 students who participated in the intervention part of the study, chose to teach physical sciences in the second teaching practice module and they were all allowed by their mentor teachers to teach Gr 11 classes. This made it possible for them to teach electromagnetism, since CAPS requires this topic to be taught in the third term.

I followed these seven students into the schools where I observed and video-recorded some of their lessons. The fact that these students all taught the topic during the same three weeks of the school calendar implied that I could not observe all of the electromagnetism lessons taught. Several factors affected the number and quality of the lessons I observed and eventually, the number of students that could be included in the data sample. One student taught at a school where the mentor teacher was not available for most of the teaching practice period and this student did not have access to the storeroom where science equipment was kept. The data collected from this student was therefore not used for analysis. I furthermore decided to use only the data of students for whom I could observe and video-record at least two lessons (approximately 60 minutes of teaching electromagnetism). These three students constituted the sample for the multiple case study on which I embarked to answer the second research question of the study:

- To what extent is TSPCK learned during the intervention, manifested in the practice of pre-service teachers as revealed during Teaching Practice?

Apart from observing the lessons of these students, I also conducted semi-structured and VSR interviews with them. The multiple approaches were employed to capture as many facets of the development of their PCK about the teaching of electromagnetism as possible. Baxter and Lederman (1999) summarised the aspects of teachers' PCK that can be elicited through research as: what teachers know, what they do and why they do it. In this study, "what the student teachers know" was determined through paper-and-pencil assessments. This is discussed in Chapter 5. What the student teachers do when they translate their knowledge into practice and what decisions they make are captured by the observations and interviews, the subject of discussion of this chapter. The quality of TSPCK, as revealed in data sources such as the current study, is influenced by the knowledge of the content specific components as well as the interaction among them (Mavhunga & Rollnick, 2017; Park & Chen, 2012). During analysis of the lessons and interviews, I searched for evidence of competent manifestations and interaction of the components of TSPCK about electromagnetism as taught during the intervention. The interviews also afforded me the opportunity to elicit the student teachers' pedagogical reasoning about their teaching, which could hardly be accessed through lesson observation only (Chan et al., in press).

One should acknowledge the fact that not all aspects of the PCK about electromagnetism that became evident during the lesson presentations, necessarily resulted from knowledge gained during the intervention. Nevertheless, there is no indication of the baseline dynamic PCK of the participants, because students did not have access to schools in the first term of the year and the dynamic PCK of the students could not be accessed before the start of the intervention. This is an inherent limitation that logistical aspects put on the design of the research.

Other obvious limitations related to observer effects (Gall et al., 1996; Leedy & Ormrod, 2005) that I had to be aware of during my analysis are listed below.

- Observational bias: What I perceived as good and effective teaching and the way I would teach the topic, as well as my eagerness to see the students applying the knowledge they had attained during the intervention, may have clouded my judgement when analysing the data. To counter this effect I designed a rubric for enacted PCK (Appendix L), which I rigorously adhered to when judging the extent and quality to which participants enacted their knowledge of the TSPCK components. Furthermore, the discussions with and input of an external moderator served to validate my judgement.
- The halo effect: I have known the participants since their third year of study when I taught them methodology of physical sciences. My positive impressions of the hardworking students in the group may have caused me to rate these students favourably. This I countered by strictly adhering to the rubric (Appendix L) designed for scoring the enacted components of TSPCK. .
- The Hawthorne effect: Students may have answered the prompts in the interviews in sympathy with the goals of my research. Since they had to sign informed consent forms to be video-recorded and interviewed, the purpose of the research was known to them (Denley & Bishop, 2010). However, the lesson observations, recordings and interviews occurred simultaneously with assessment activities that were part of the teaching practice module for all students. Consequently, the students were accustomed to being observed and to discuss their lessons honestly and openly with lecturers.
- Another effect that may influence the validity of especially the data collected by VSR interviews, is mentioned by Denley and Bishop (2010, p. 110). They argue that, "if much of the knowledge about practice is tacit", then teachers may not be able to explain or even remember the reasons for the behaviour in which they engaged. Since the participants in this study were inexperienced, it can be assumed that they made their decisions about teaching consciously and intentionally and would therefore be able to recall most of their thinking. The VSR interview also assisted in bringing reflection on decisions to the fore.

Assessment of the extent and quality of the enactment of TSPCK is not based on the lessons only, but also on the students' comments during the VSR interview. It is not the purpose of the study to measure the dynamic PCK as such, but to establish students' ability to apply and enact the knowledge gained during the intervention. Therefore, the quality of TSPCK as revealed *in action* (lesson observation) and during reflection *on action* (VSR interview) are judged to determine to what extent the student enacted the knowledge gained during the intervention. As mentioned earlier, a limitation of the study is that the students' *dynamic* PCK in this topic was not investigated before the intervention, only their declarative PCK, as reported in CoRes. Furthermore, the post-CoRes were written approximately three months prior to the teaching practice period and students may not have recalled what they wrote in those CoRes. Therefore, I could only conclude which of the aspects of the TSPCK components addressed in the intervention became visible during the lessons and interviews. I could not make assumptions about the extent to which these aspects would have appeared had the student not attended the intervention.

An excerpt of the rubric for the components *Representations* and *Conceptual teaching strategies* can be seen in Table 6-1 (p.120). Not all components are applicable in all phases of a lesson and in such instances these components were not scored. The scores allocated for each section of a lesson is indicated in the lesson narratives included as an appendix.

Table 6-1: Excerpt from the enacted TSPCK rubric (Appendix L)

Components	Restricted	Adequate	Rich
Representations	• Relies mostly on explaining and telling. • The use of representations is restricted to drawings also available in textbooks.	• Use of representations restricted to one type of representation only. • Uses objects as illustrations or artefacts. • Uses a representation with no apparent conceptual development in learners.	• Makes extensive use of representations in combination e.g. video and diagrams or demonstration and diagrams. • Uses representations to support understanding of concepts. • Uses representations effectively to stimulate conceptual reasoning.
Conceptual teaching strategies	• Questions elicit chorus or yes/no responses. • Answers own questions before learners make an attempt. • Ignores learners' answers when not in line with the expected answer. • Does not show awareness when learners reveal the existence of misconceptions. • Does not make an effort to incorporate representations to support conceptual understanding.	• Questions asked mostly require rote learning • Answers own questions after only one or two attempts by learners – does not rephrase questions. • Addresses misconceptions through procedural teaching. • Uses representations in combination with direct instruction – telling learners what they are supposed to see or as confirmation of theory only.	• Shows an attempt to work towards problem solving and inquiry. • Asks questions that elicit learner thinking and require conceptual reasoning. • Shows creative interaction of pre-concepts. • Shows awareness of typical learner errors and misconceptions works towards conceptual change. • Uses a variety of representations with logical sequencing in combination with appropriate questions. • Waits for responses and does not answer own questions; rephrases questions.

Table 6-2 gives the Rasch person locations of the post-CK tests and CoRes of the class of 14 who participated in the first part of the study. The students for whom I observed and video-recorded at least two lessons that are included in the data analysis of this chapter, are students NB, NL and HS. The last two columns of the table show the rankings of these three students in the class of 14. Coincidentally, the three students participating in the second phase of the study ranked amongst the top four for level of CK, yet, they were spread out in terms of their level of reported TSPCK (post-CoRe).

Table 6-2: Ranking of participants in the second part of the study

Student	Gender	Person locations (post-CK test)	Person locations (post- CoRe)	Post–CK test (ranking)	Post-CoRe (ranking)
NB	F	3.22	0.756	1st	3rd
HS	M	2.624	0.483	2nd	5th
MS	F	1.861	0.756		
NL	F	1.574	-2.442	4th	13th
BM	M	1.574	-1.649		
AW	M	1.091	-1.649		
MW	F	1.091	1.047		
HD	F	1.091	3.121		
DK	M	0.878	-1.649		
JD	F	0.878	0.225		
KM	F	-0.097	-0.951		
LM	M	-0.295	-1.411		
TM	M	-0.718	-0.723		

In §6.2.1 I give an extensive presentation of results collected from student NB and a complete description of my actions and reasoning during the analysis of the data of three of the sections of her teaching. Sections 6.2.2 to 6.2.3 provide condensed descriptions of the results and analysis of the other two students. For each of the students in this case study the following is available in electronic appendixes: lesson narratives with coding and scores and interview transcripts.

6.2 Analysis of the video-recorded lessons and VSR interviews

During the analysis of the data sources for this part of the study, I took the following steps:

- I watched the video recordings at least twice to get an overview of the lessons.
- Following this, I wrote a narrative account of the lessons of each of the students and divided the lesson into *teaching sections* normally lasting three to 12 minutes and following one another chronologically. Each section typically entailed one of the following:
  - assessment of the knowledge already in place (from previous teaching or learners' own experience);
  - the teaching of a new single key idea or sub-ordinate idea (see Appendix H for key ideas);
  - consolidation of concepts recently taught; and
  - discussion of exercises given as class or homework.
- I then identified *teaching events* that occurred during a specific section and studied these for evidence of the enactment of one or more of the TSPCK-related aspects discussed during the intervention. These were coded in Atlas.ti with the TSPCK components as predetermined codes. The lesson videos were not transcribed, since the Atlas.ti software enabled coding and analysis of videos. Codes that were used to describe the events and the evidence that would typically lead to such codes are listed in Table 6-3. When situations emerged that could not be related to the codes mentioned above, additional explanatory codes were used. The teaching events were numbered and when more than one of the components were evident during the same event, they were allocated the same number. These numbers were also transferred to the lesson narrative to enable the reader to link teaching events from the video to the narrative.

Table 6-3: Codes used in the analysis of lessons using Atlas.ti

Codes used in ATLAS.ti	Examples of evidence
Curricular saliency (**CS**)	• The student reveals knowledge about the sequencing of concepts. • The student displays an awareness of the knowledge that should be in place before a certain concept is taught. • The student is aware of the application of the concept in real life and uses it in the lesson.

Codes used in ATLAS.ti	Examples of evidence
What is difficult to teach (**WDT**)	• The student reveals and uses knowledge about the way learners think and concepts that learners find difficult to understand
Learner prior knowledge (**LP**)	• The student reveals and uses knowledge about typical misconceptions and other ideas learners have, pertaining to the topic.
Representations (**RP**)	• The student uses a representation (demonstration, video, analogy, simulation and/or diagram) to support the explanation of a specific concept.
Conceptual Teaching strategy (**TS**)	• The student's knowledge of a teaching strategy in terms of sequencing of concepts and use of representations is evident. • The student uses questioning in the pursuit of conceptual development • The student uses questioning and discourse in combination with knowledge of typical misconceptions and representations to support conceptual change. • The student integrates other components creatively and effectively into a conceptual teaching strategy.

- The teaching events were gauged against the rubric for enacted TSPCK (Appendix L) and a level (*restricted, adequate or rich*) representing the quality of the enactment, was assigned for each component. Validation of the rubric took place when an expert science teacher educator also scored three events of student NB. The expert and I compared and discussed our scores until we had reached agreement and the rubric was refined where necessary.
- Furthermore, each event was compared to the themes of the intervention to determine whether there was a link between the teaching events and the themes. The last two steps enabled me to judge the extent of the enactment of knowledge attained during the intervention; keeping in mind the limitation mentioned in the introduction to this chapter.

After the students had completed a full cycle of teaching electromagnetism, they were interviewed. One part of the interview was semi-structured and prompted the students to reflect on general aspects of their teaching and how they enacted their TSPCK. The second part was a VSR interview during which the students were asked to view sections of their lessons and comment on their actions and decisions. For this interview, I selected three or four sections in the lessons of each student that revealed interesting aspects of their teaching and could be related to key ideas in their post-CoRes. Time restrictions did not allow for more. I again used the codes listed in Table 6-3 to code the students' comments in the VSR interview; for example, if a student reflected on the use of a representation in the lesson episode, that comment would be coded "representation (RP)". Comments by the students that had no direct bearing on one of the TSPCK components but rather on general pedagogy were coded "reflection". During the interview the students were reflecting *on* their actions, which is described by Gess-Newsome (2015) as a manifestation of a teacher's personal PCK (see framework in § 2.4). Aspects that emerged from the students' semi-structured interview which were not specifically linked to a specific section or event but revealed their thinking about specific TSPCK components and their pedagogical reasoning about their teaching of electromagnetism for the first time, are discussed separately.

6.2.1 The case of student NB

The analysis of the results of student NB will be discussed in detail to give the reader an idea of the thinking and analyses that were employed.

Student NB did her teaching practice at a private high school for girls. The school was adequately resourced, although the venue where she taught was a normal classroom with limited space for hands-on activities. The Gr 11 class she taught had 25 girls and was the only Gr 11 science class in the school. I observed and video-recorded two of her lessons on electromagnetism. Her final lesson in the topic, where she covered Faraday's law and magnetic flux, was not observed. In the two lessons, ten sections were identified and these are briefly described below.

Section 1: (First lesson starts) Revision of knowledge that should be in place: Comparing magnetic and electric fields. [Time 5 min 50 s].

Section 2: Teaching a new key idea: The magnetic field around a current-carrying conductor. [Time 7 min]

Section 3: Teaching sub-ordinate ideas: The magnetic field around a loop and solenoid. [7 min 30s]

Section 4: Real-life application of a current-carrying solenoid: The electromagnet (without using a representation). [2 min 20 s]

Section 5: Review and discussion of a class exercise. [12 min 15 s].

Section 6: (Second lesson starts) Revision of knowledge that should be in place: Concepts from previous lesson. [6 min 20 s]

Section 7: Re-teaching of the electromagnet (using a demonstration). [3 min 40s].

Section 8: Teaching a new key idea and sub-ordinate ideas: electromagnetic induction and factors that affect the induced current. [6 min 30 s]

Section 9: Discussing answers to exercise. [2 min 30 s]

Section 10: Teaching a sub-ordinate idea: *Lenz's law.* [8 min 25 s]

Atlas.ti outputs that were created from student NB's lessons, show the sections of her lessons, the evidence collected during each section and the comments from the VSR interview (Electronic Appendix NB) related to the selected sections . Selected Atlas.ti outputs for three specific sections (sections 2, 4 and 7) will be discussed in the following paragraphs. These were selected because of the rich data they presented in terms of the evidence of student's NB enactment of her learned PCK about electromagnetism. The detailed discussion of data collected from this student serves to give the reader insight into the reasoning that was followed when the extent to which the student enacted teacher knowledge, was considered.

6.2.1.1 Results from Section 2 of student NB

During section 2, student NB taught the key idea using video and simulations extensively. The lesson narrative of this section is given below (Figure 6-1) and is followed by Figure 6-2 (p. 126) showing the coding of events during this section in Atlas.ti. The coded events in the video are indicated in the narrative in colour where they occurred.

Section 2
Teaching a new key idea: *The magnetic field around a current-carrying conductor.*
[Time 7min]

Student NB asks an introductory question to the new concept: "What is the connection between electric current and magnetism?" The learners do not give satisfactory answers. (2.1) She leaves the question hanging and presents a video that shows how compasses deflect when placed around a current-carrying conductor. She draws learners' attention to the deflection of magnets when the circuit is closed. She asks questions to which learners respond in chorus: (2.2) "Do they all point in one direction? (No) Did they change direction? (Yes)."

Student NB draws a diagram on the board that indicates a wire carrying current out of the board and explains to learners a "dart-analogy" to remember which directions of current the cross [⊗] and dot [⊙] represent.(2.3) She depicts the 3D video picture in a 2D diagram on the board. (2.4)

She proceeds with a video showing the behaviour of iron filings around a current-carrying conductor (2.5) and then introduces the RHR and warns that if they use their left hands they will get the wrong answers. (2.6)

Figure 6-1: The lesson narrative of Section 2 of student NB

I used the *network manager* of Atlas.ti to display the codes for a specific section in one view, together with the related comments and remarks from the VSR interview. Such a network view for Section 2 of student NB's lesson is displayed in Figure 6-3.

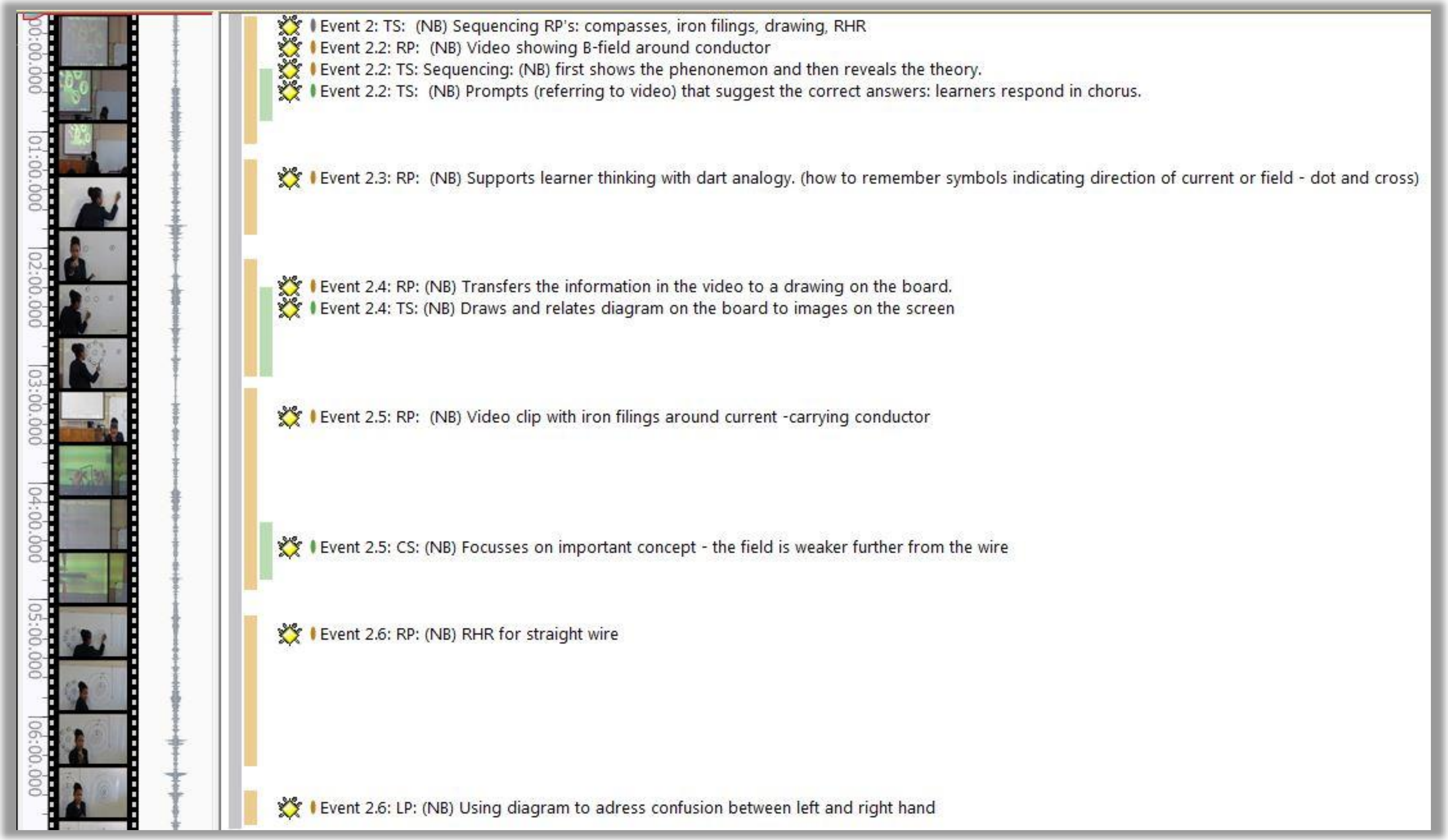


Figure 6-2: Atlas.ti window showing the coding of Section 2 of student NB

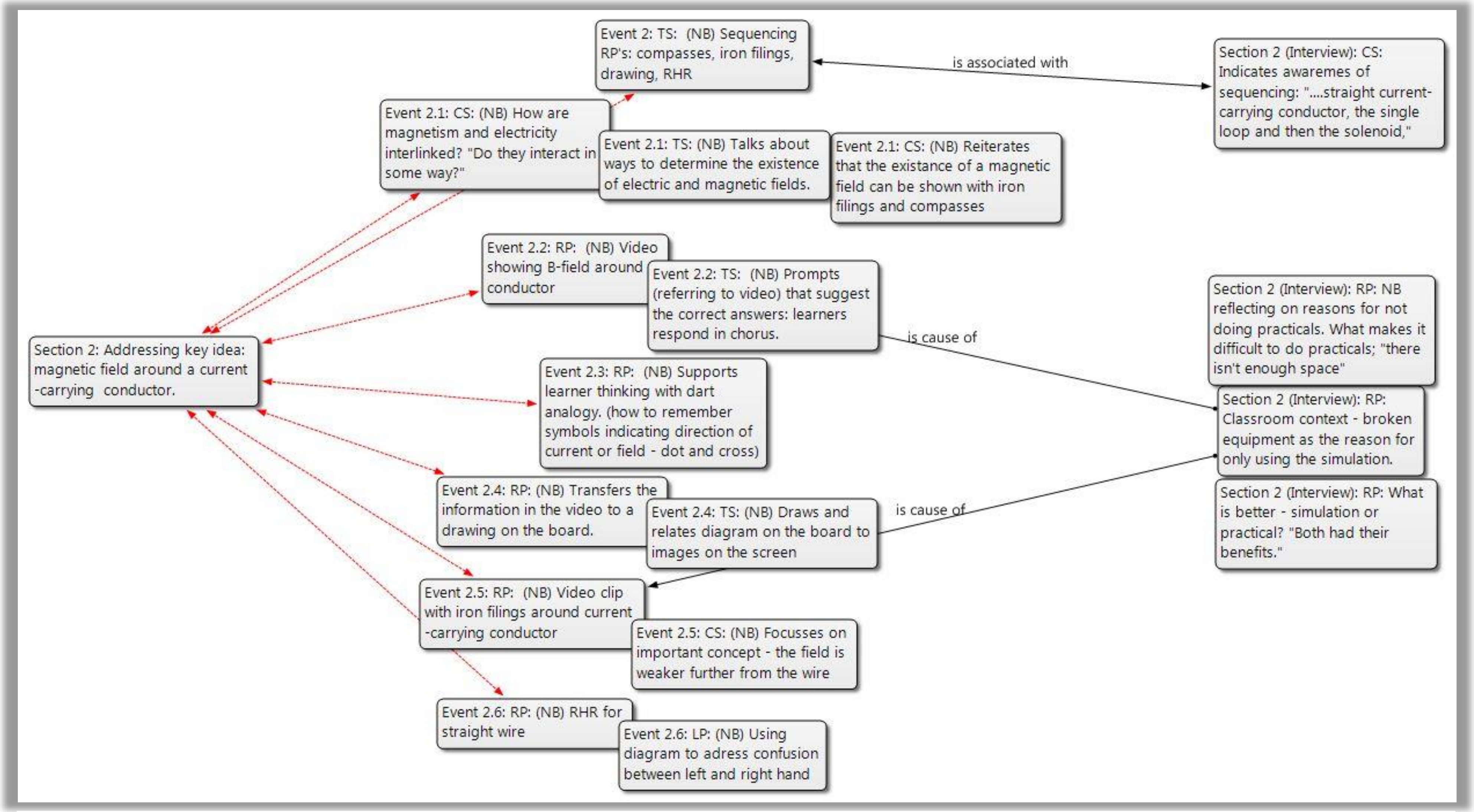


Figure 6-3: The Atlas.ti network view of Section 2 of student NB's lesson

Discussion of components related to Section 2 of student NB

Curricular saliency:

During this teaching section where student NB taught the key idea: *magnetic field around a current–carrying conductor*, her knowledge of the sequencing of concepts became evident when she made sure that learners understood that the existence of a magnetic field could be established by using compasses or iron filings. The purpose was that learners could appreciate the behaviour of the compasses around a current-carrying conductor. She did not tell them beforehand that a magnetic field exists around a current-carrying wire, but presented the video simulation and let the learners observe the deflection of the compasses. Furthermore, she drew learners' attention to the fact that the magnetic field gets weaker as the distance from the conductor increases, even though understanding of this idea would only become essential when teaching the change in magnetic flux. This student's knowledge of curricular saliency was therefore rated **rich**.

The ideas concerning the curricular saliency that became evident in student NB's teaching during this event, were explicitly discussed in themes 2 and 4 of the intervention.

Learner prior knowledge:

Student NB was aware of the fact that learners may not realise the necessity of using their right hands when applying the RHR, an issue that was addressed in theme 5 of the intervention. She used a diagram (Figure 6-4) on the board to convince them that using the left hand resulted in wrong answers. She expected learners to work with her and use both their right hands and left hands to see the difference in outcome. This showed **rich** knowledge of learner thinking and possible misinterpretations.

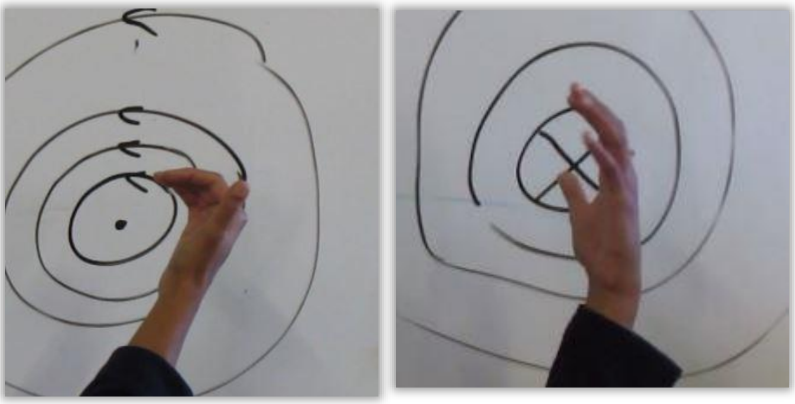


Figure 6-4: Student NB explaining the difference between using the right and left hands

Representations

Student NB made effective use of a video during section 2, which showed a straight conductor with four compasses placed around it and clearly displayed the change in orientation of the compasses when the current was switched on (Figure 6-5). Her application of this representation was further developed when she transferred the picture in the video clip to the writing board in a diagram, capturing the essence of the concept and enabling her to proceed to the explanation of magnetic field lines and the RHR.

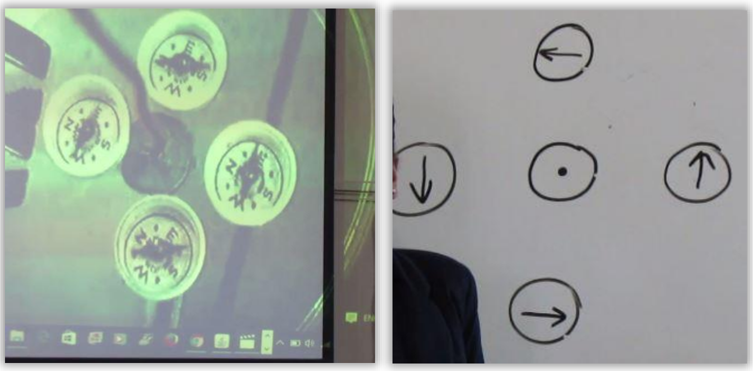


Figure 6-5: Combination of representations by student NB

She used the analogy of a dart (discussed in theme 5 of the intervention) to give learners a method to remember which direction of current a dot [⊙] or a cross [⊗] diagrammatically represents: "*When you throw it* [the dart] *away from you, you see that part* [the crossed feathers] *of a dart going away from you…*" By means of an unanimous "*Ahhh*" the learners showed their understanding of and appreciation for this explanation.

Student NB proceeded with a video clip showing the behaviour of iron filings around a straight conductor. She used this representation to convince learners that the magnetic field is stronger closer to the wire, since the magnetic field pattern is less pronounced further away from the wire.

She showed a preference for using videos rather than actual demonstrations. During the VSR interview with her (see interview comments in Figure 6-3), this issue was raised and she responded as follows:

> *The solenoid that we had in class, it was broken, so it was like, everything had come out. So I think that I may have preferred to do the actual practical, the investigation, …but I think that this, the videos might have helped, in the sense that in that class, when they're standing around the table, because there isn't enough space, not everyone can really see. ... And I think*

that even that (the practical) *would've helped them to remember. But I think that both had their benefits.*

Student NB was aware of the practical demonstrations that could be done, but adapted to her situation and decided to use video recordings. Student NB's knowledge and use of representations was scored **rich**.

Conceptual teaching strategy

When assessing the student's knowledge of this component I searched for evidence that the student was able to integrate other TSPCK components effectively into a teaching section to attain conceptual development and conceptual change. Attaining conceptual change means the student teacher manages, through questions, discourse and other methods, to replace existing learner misconceptions with scientifically acceptable ideas (Duit & Treagust, 2003; Hewson, 1992).

One of the main features of student NB's conceptual teaching strategy was her apparent awareness of the importance of sequencing and scaffolding of concepts, that is, she integrated her knowledge of curricular saliency of the key ideas effectively into teaching. To teach learners about the magnetic field around a straight current-carrying conductor she first made sure that learners understood that the presence of a magnetic field could be indicated by compasses and iron filings. She then sequenced the uncovering of this key idea as follows: first the straight current-carrying conductor and the application of the RHR, then a current-carrying loop with the application of the RHR and lastly the solenoid and the application of the RHR for a solenoid. This sequencing of the sub-ordinate ideas was discussed during the intervention in themes 2 and 6.

As explained earlier student NB integrated various representations in her conceptual teaching strategy of the key idea while addressing difficulties learners may encounter. She exposed learners to the phenomenon of the magnetic field around a current-carrying conductor and alerted learners to the important aspects through discourse, before she gave the formal theory.

Student NB varied her method of questioning from eliciting yes/no answers chorused by the class (see lesson narrative Figure 6-2) when drawing their attention to important aspects, to asking open-ended questions that she rephrased, working towards conceptual development, until the learners answered satisfactorily. Her pacing during this section was rather fast, as she commented in the VSR interview:

> *I think it would have,…watching it now, I couldn't keep up with myself. So, I think that I just moved too fast….. So I needed to go much slower, I think. I think I was just prepared, I wanted to get things done, and I had all these ideas in my head, and I wanted to throw them out. But in terms of the sequencing, especially in this part, I'd just kept it the same.*

Student NB's enactment of a conceptual teaching strategy to explain this key idea, integrating her knowledge of scaffolding, representations and learner thinking and her ability to reflect honestly on her actions were evident. As such, this component was scored **rich.**

6.2.1.2 Results from Sections 4 and 7 of student NB

During section 4, student NB attempted to explain the electromagnet as an application of the magnetic field around a current-carrying wire. She did not use an actual demonstration, but tried to convey the concept through questions and answers. The learners did not respond well and she commented in the VSR interview that she was not satisfied with this part of the lesson. She decided to reteach this with a demonstration in the follow-up lesson (section 7). The lesson narrative of these two events is shown in Figure 6-6. Figure 6-7 shows the network view displaying the significant events during these two sections and the interview comments related to the events.

Section 4
Real-life application of a current-carrying solenoid: *The electromagnet*
[2 min 20s]

Student NB asks learners about the advantages of the solenoid that behaves like a magnet when it carries current. (4.1) Learners do not respond. She shows a PhET-simulation of a solenoid connected to a cell.
Because of the lack of response, she senses that the girls are not with her: "Are you scared girls…or do you not know what's going on?"
She goes on explaining how the strength of an electromagnet can be changed (4.2). The bell rings for the end of the first half of the double period.

She then hands out an exercise sheet with ten multiple-choice items that learners have to work on individually in class. The questions relate to the content of sections two, three and four. The learners are given approximately 13 minutes to complete the exercise.

Section 7
Re-teaching of the electromagnet
[3 min 40s]

One of the questions in the exercise given during the previous lesson (Section 4) is based on the electromagnet. Student NB uses that as an introduction and asks learners whether they know what an electromagnet is. (7.1) The learners admit that they don not know and that they guessed the answer to the question. Student NB demonstrates an electromagnet. She uses an iron nail with thin insulated copper wire wound around the nail. She connects the copper wire to a cell and picks up paperclips with the nail. (7.2)
Throughout the demonstration, she asks questions to support conceptual development. She waits for the learners to answer.
"What is iron?" Answer*: Ferromagnetic material*
"How can I magnetise iron?" Answer: *By a magnetic field*
"So what happens to a nail if I put it inside a solenoid?" Answer: *It becomes magnetised*. (7.2)
She then proceeds to show pictures of real-life application of electromagnets. (7.3)

Figure 6-6: The lesson narrative of Sections 4 and 7 of student NB

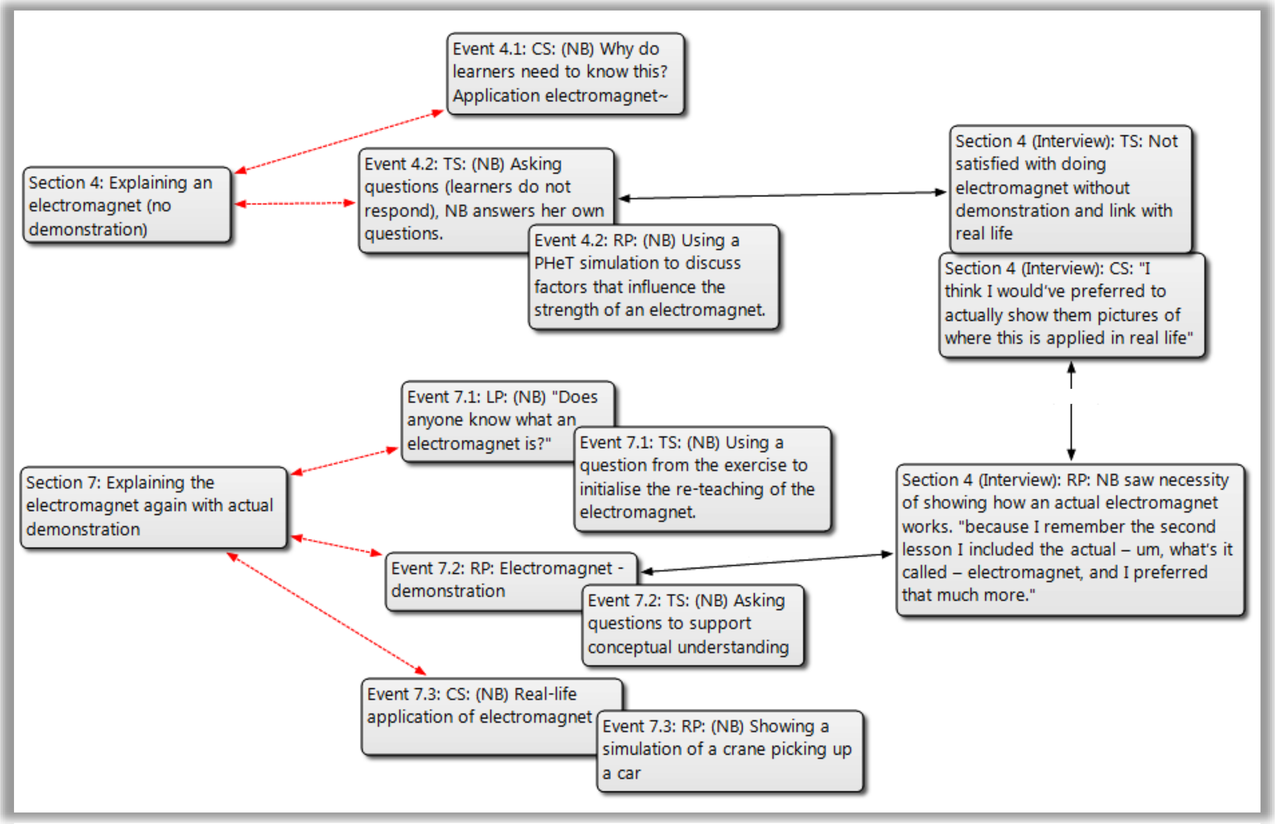


Figure 6-7: The Atlas.ti network view of Sections 4 and 7 of student NB's lesson

Discussion of components related to Sections 4 and 7 of student NB

Curricular saliency

In the curriculum document (CAPS), making an electromagnet is suggested as a project when teaching the magnetic field around a current-carrying conductor. Student NB did not include the project in her initial attempt to teach the concept, but used a PhET simulation (see Figure 6-8) as a demonstration of an electromagnet. The simulation did not show that the electromagnet could be used to attract magnetic materials.

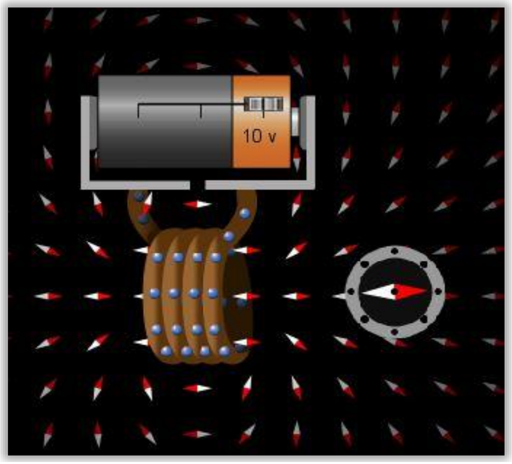


Figure 6-8: Clip from a PhET simulation used by student NB

Learners were very unresponsive when she inquired about methods to increase the strength of the electromagnet. She ended up answering her own questions and eventually gave the learners an exercise about the magnetic field around current-carrying wires to do in class. Since she understood the importance of learners understanding this application of electromagnetism in real life, she retaught this concept in section 7, during which she attempted a different approach. For this reason, her knowledge of the curricular saliency of the key idea was scored **rich**.

Learner prior knowledge:

In section 7 student NB expected learners to have some prior knowledge about the electromagnet, but soon realised that her teaching during section 4 had not been effective and that there was a gap in the learners' knowledge of the concept and she proceeded to reteach it. Handling such a situation was not explicitly discussed during the intervention and should be assigned to her inherent ability to reflect about her teaching. As such, this component for section 7 was scored **rich**.

Representations

Although student NB used a representation during section 4 (the simulation shown in Figure 6-8), its effective use was restricted by her lack of knowledge of learners' understanding of the governing principles of an electromagnet. When she discussed the exercise given to the learners, she realised that they had no understanding of this concept.

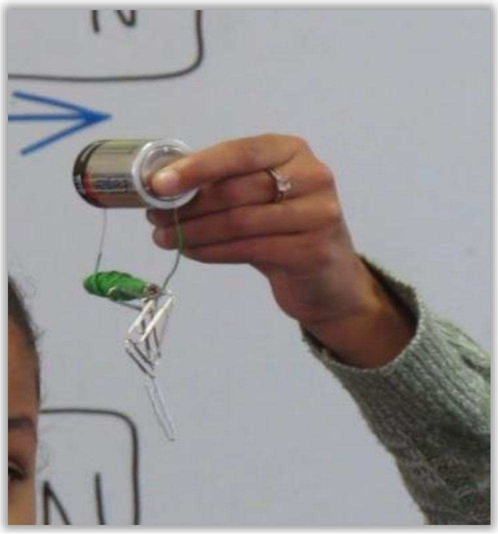


Figure 6-9: Student NB doing an electromagnet demonstration

Her re-teaching of the concept involved the demonstration of an actual electromagnet, which she made using an iron nail with copper wire wound around it. She connected the wire-ends to a single cell and picked up a few paperclips with the electromagnet (see Figure 6-9). The learners indicated their amazement and comprehension of the effect with an "*Ahhh*". Although student NB's knowledge and use of representations in section 4 were merely adequate, in section 7 these were scored **rich**.

Conceptual teaching strategy

Student NB realised the flaws in her teaching strategy in section 4 and expressed her dissatisfaction as follows:

> *I remember the second lesson I included the actual electromagnet, and I preferred that much more. I think over here [*Section 4*], I don't know, it was towards the end of the lesson, and then you just start to do things, but even the – my sequencing, so going from the application, I think I would've preferred to actually show them pictures of where this is applied in real life, and that sort of a thing, so , I don't think I'm satisfied with this part.*

This quotation is evidence of student NB's ability to reflect on her actions, evaluate the effectiveness of her teaching and propose an alternative. As remarked by Krepf, Plöger, Scholl, and Seifert (2018) such reflective activities during an interview make the PCK of a teacher "visible".

She displayed a well-developed questioning technique, encouraged during the intervention, when she guided learners' thinking about the electromagnet. While doing the actual demonstration, she waited for their responses to her questions and confirmed correct answers. She integrated her use of the representation skilfully with questions eliciting learner prior knowledge and development of the new concept (see the lesson narrative in Figure 6-6). Her new strategy, which was evident in the interaction of effective representations, knowledge of learner difficulties and questioning, developed as a result of her experience during Section 4. Regarding her teaching of the electromagnet student NB's knowledge of conceptual teaching strategy improved from restricted in section 4 to **rich** in section 7.

6.2.1.3 Evidence from student NB's interview

In this section I discuss evidence of student NB's ability to reflect on her teaching that emerged from her interview but was not specifically linked to any of the teaching events in her lessons.

Student NB's thinking about the curriculum and the content

To be able to decide how to spend their time teaching a topic optimally , teachers need to be able to differentiate between important fundamental concepts in the curriculum and inconsequential ideas (Friedrichsen et al., 2009). It was evident that student NB was confronted with this during her very first experience of teaching electromagnetism:

> *I think I would've liked to know how deep to go into the topic. You know, in the sense of like, how thoroughly they need to understand. I think that will make a big difference, teaching the grade twelves, because at the moment, like I said, my teacher was able to tell me; you don't need to go so deep into whatever, whereas myself I would never have known.*

The student also found it challenging to balance the time spent on certain concepts with the requirements of the curriculum and examinations. She voiced her concern that she may have spent too much time revising the basic ideas and not enough on the calculations based on Faraday's law:

> *I think I spent too much time revising this section* … [the examination] *is not based on a lot of this, you know. So I don't know if I did a good thing, or if I should've maybe rushed towards the end where we did Faraday's law that so that we could* ***concentrate on calculations*** …
>
> *– so I do think that the concepts are more important, and I think that once the learners understand the concepts … I just think that the way the curriculum wants you to assess them, … the way they are tested, it* ***actually doesn't matter whether they understand or not****, you just need to know how to solve the problems.*

Student NB's perception is clearly that learners will be able do the problems in the examination even without sound conceptual background:

> *… my teacher showed me one of the past exams set by the government and everything, for the grade elevens, and* ***it was very simple, and it counted so little …***

This corresponds with a finding from a study by Rollnick et al. (2008) that teachers' emphasis on procedural strategies is not merely the result of poor CK, but may be the product of conceptual factors such as, in student NB's case, curriculum and external examination demands.

Revealing knowledge of curricular saliency, student NB reflected on the sequencing of concepts such as magnetic flux and induced current and considered changing the sequencing when teaching it again:

> *Although, I was thinking that maybe, it would've helped, to teach magnetic flux right at, not right at the beginning, but before actually doing the magnetic-field-induces-current thing. But I didn't do that, though.*

Student NB's thinking about what is difficult to teach and learner difficulties

When prompted in the interview about concepts she found difficult to teach she replied:

> *Magnetic flux. I found magnetic flux quite difficult. I think out of everything, even the Lenz's law stuff. That was something I actually only understood for the first time this year, the whole… north, south pole, the reason why it induces, that whole thing … I don't know why but I found it quite difficult.*

This student was acutely aware of the fact that she did not understand this topic when she herself was a learner:

> *In all honesty, I think, when I think of what I knew before the methodology course, compared to after, there was a lot of like gaps, you know*? *Like I even look back at grade eleven and I think I actually knew nothing. I don't know how I got the marks I did. I think we just crammed, not understanding anything.*

When prompted about what she learned during her teaching experience regarding learners' thinking and misconceptions, she remarked:

> *There isn't anything like, very new that I think I've learned. Because what happened is that during the methodology, I learned of my own misconceptions, and based on those misconceptions, I basically, when I was teaching, those were the points that I focussed on.*

These answers attest to the contribution the methodology module made to her knowledge about misconceptions and learner difficulties on which she based some of her decisions when she assessed learners' prior knowledge:

> *I think a lot of the stuff that I based it on was stuff that* ***I*** *didn't know….. But I thought it was important because from my own experience, it was stuff that I didn't really know, or stuff*

that I skipped, and then I thought that, well, it might be important to some of them to go from where they were to where we needed to go.

As a pre-service teacher her own experiences when learning science contributed to her knowledge of learner thinking and how to use it to transform the content to be conceivable for the learners. This concurs with findings by Eick and Reed (2002), reiterated by Friedrichsen et al. (2009).

Student NB's thinking about representations

When she was prompted in the interview about her preference for using video clips and simulations instead of demonstrations, she indicated both the lack of equipment and herself being intimidated by the equipment as factors that played a role:

> *… I **really wanted to do the actual practical**, but the magnets that were there were not magnetised anymore. They were not magnetic. And then, also there was also quite a nice, … one of the solenoids? There was one of those, but it had like been broken, and everything. And **I was also just a bit intimidated by the equipment**, so I thought, let me just go for the simulations.*

Her absence during the intervention session where demonstrations were presented and discussed (also mentioned in §5.3.4, p.112) may account for her being uncomfortable with the equipment.

Student NB's thinking about teaching strategies

The impact of her own experiences as a learner is evident in her remark about her decision making when she was teaching.

> *… like from grade eleven I can't even remember how it was taught to us – 'cause a lot of the stuff, when I'm teaching, I reflect on how I was taught it, and how I can make improvements."*

She also commented on a strategy suggested by her mentor teacher:

> *… it's actually something that my mentor teacher said I should do, since they do work from the textbook, to link what I'm teaching to the textbook, so when they go back, what's in the textbook isn't unfamiliar. I might not be teaching it in that sequence or whatever, but I am drawing an image on the board … see that it is similar to the one in your textbook."*

Student NB's lessons presented evidence that she was able to employ her knowledge of the components of TSPCK as these pertained to her teaching. In some instances, it may have been tacit and unintentional, but she was able to reflect rationally about them during her interview.

6.2.2 The case of student NL

Student NL was mentioned specifically in the previous chapter, because she was the only participant whose post-CoRe did not show an improvement on her pre-CoRe and I believed an investigation into her ability to enact her knowledge might shed light on her relatively poor performance in both her CoRes. She did her teaching practice at a well-resourced prestige government school for boys. She taught two Gr 11 classes with approximately 25 learners per class. I observed two lessons taught by this student on electromagnetism. In the first lesson, she introduced electromagnetism and taught the key idea of a magnetic field around a current-carrying conductor. The subsequent two lessons, during which she taught the magnetic field of a solenoid and Faraday's law, were not observed. In her last lesson she addressed the concept of magnetic flux. A narrative of her lessons can be found in the electronic Appendix NL. In the two lessons that were observed and recorded, the following sections were identified:

Section 1: (First observed lesson starts) Revision of knowledge that should be in place: Comparing magnetic and electric fields. [5 min]

Section 2: Teaching a new key idea: *The magnetic field around a current-carrying conductor*. [12 min 45 s]

Section 3: Teaching a sub-ordinate idea: *The magnetic field around a loop and solenoid.* [7 min 30 s]

(A lesson about electromagnetic induction and Faraday's law, which was not observed or video recorded, followed.)

Section 4: (Second observed lesson starts) Revision of knowledge that should be in place: Concepts related to Faraday's law taught in previous lessons. [9 min 35 s]

Section 5: Teaching a key idea: *magnetic flux*. [15 min 10 s]

Section 6: Dealing with a textbook problem on Faraday's law. [2 min 45 s]

Examples from the data collected and analysed from student NL's lessons is presented below and are followed by a discussion on the student's knowledge of the TSPCK components as enacted in the observed lessons and reflected on in the interviews.

6.2.2.1 *Results from the teaching of student NL*

As an example of Student NL's teaching, results from section 2 are presented. The discussion that follows will, however, also consider evidence from other sections of her teaching included in the electronic appendix Y. During section 2 of her first lesson student NL taught the key idea *magnetic field around a current-carrying conductor*. The lesson narrative of this section (Figure 6-10) is followed by the Atlas.ti window showing the coding of the teaching events in this section (Figure 6-11).

Section 2
Teaching a new key idea: *The magnetic field around a current-carrying conductor.*
[Time 12min 45s]

Student NL initiates the teaching of this key idea by asking the learners whether they believe that there will be a magnetic field around a current-carrying conductor and then proceeds to "prove" it by means of a demonstration. [2.1] She then asks: "What does a compass do when it is in a magnetic field?" A learner refers in his response to the "positive pole" of a magnetic field. She immediately corrected him by reminding the class that magnets do not have positive and negative poles. [2.2] She concludes that compasses align themselves with the magnetic field.

She explains that she is going to place three compasses around a wire connected to a power supply so current will flow through the wire, and says: "Then we will see if the compasses react. If they do react then we know there is a magnetic field." [2.3]

She divides the class in two groups and demonstrate to one group at a time. She points out the different components of the equipment and places compasses around the conductor. [2.4] When closing the circuit she draws learners' attention to the deflection of the compasses. [2.5]

She proceeds by explaining that this particular demonstration links current electricity and magnetism that leads to the topic *electromagnetism,* which she writes on the board. [2.6]

She asks learners to copy a diagram from the board into their scripts representing the apparatus used for the demonstration and to indicate the magnetic field on the diagram.

She then uses the diagram to introduce and explain the RHR and addresses the confusion between the use of the left- and the right-hand. [2.7] She explains how learners can use the dart analogy to remember what the dot and cross represent in terms of current direction and use this to draw diagrams on the board representing a wire with current perpendicular to the plane of the board. [2.8]

Figure 6-10: The lesson narrative of Section 2 of student NL

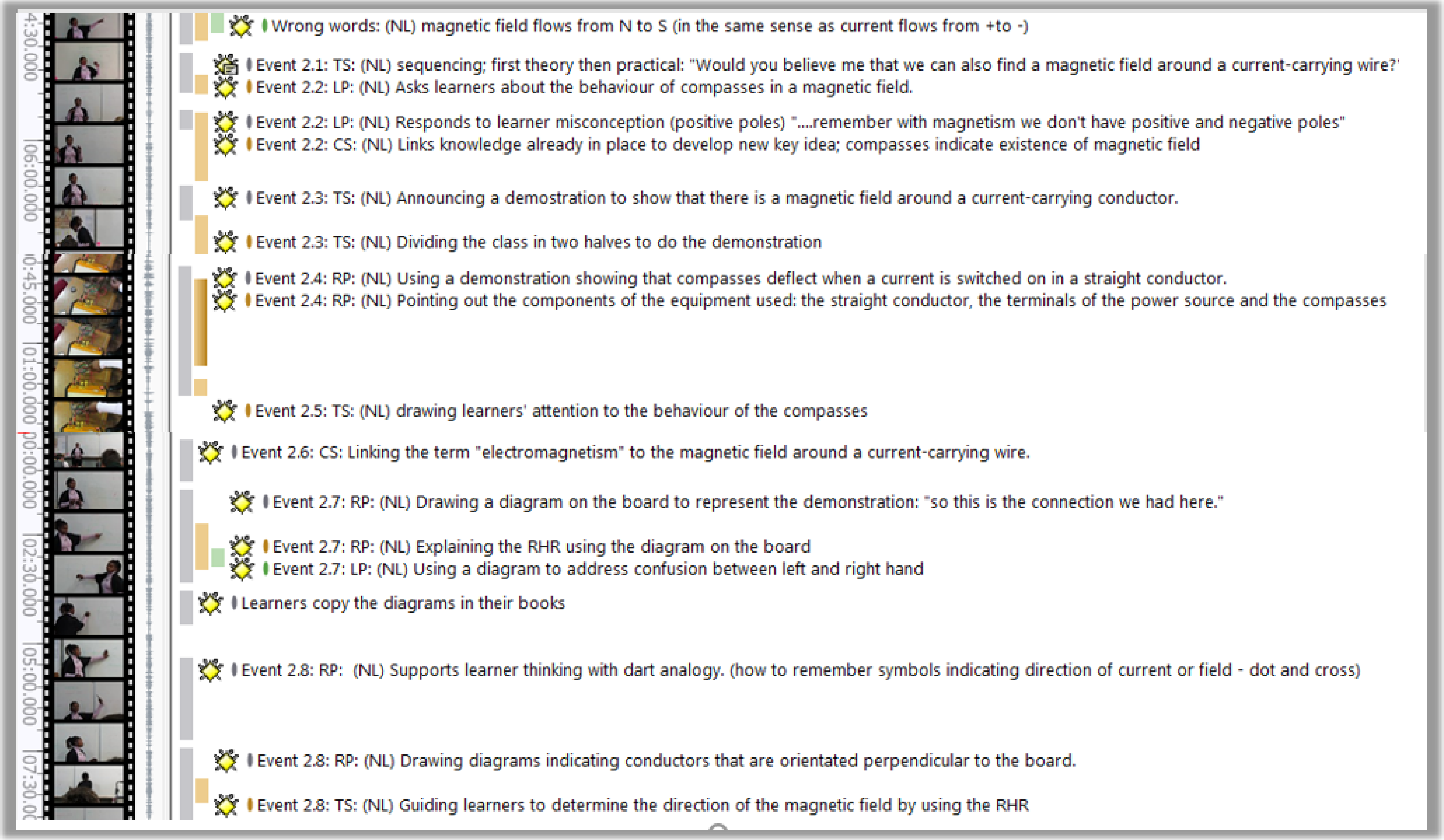


Figure 6-11: Atlas.ti window of section 2 in student NL's first lesson

Discussion of components related to the lessons taught by student NL

In the discussion below evidence from the sections described in Students NL lessons and her VSR interview, as it pertains to the five TSPCK components, is described.

Curricular saliency:

In section 2 student NL showed understanding of the sequencing of concepts in the curriculum by building on knowledge already in place to develop new ideas. She verified learners' understanding of the behaviour of compasses in a magnetic field and affirmed that learners realised that compasses could be used to indicate the existence of a magnetic field. When moving on to explaining the field around a current-carrying loop, she realised the importance of explaining the direction of the field in the centre of the loop, since the field of a solenoid builds on this idea. In this section student NL's knowledge about curricular saliency was evident in the way she sequenced and scaffolded the concepts and was scored **rich**.

During the intervention, I discussed the sequencing of the concepts *magnetic flux*, *induction of current* and *Faraday's law* and alluded to the advantages of teaching magnetic flux before the equation of Faraday's law was introduced. However, according to her interview, student NL taught Faraday's law before teaching the idea of magnetic flux. Afterwards she realised it was not effective as can be concluded from her remark during the interview:

> *In Faraday's law, they… they had a lot of questions, had a lot of, I don't know,… but there was just a confusion in their faces, when I was trying to explain the meaning of the negative sign in front of the equation, and also, when I had to – because I, I did Faraday's law before magnetic flux.*

When prompted about the way she would sequence her teaching of electromagnetism in future, she responded:

> *I would start – the magnetic field, and the current, the directions of the magnetic field, and the current in a wire, with the different orientations, of a wire, like with a straight wire, a coil, and then a solenoid. Then from a solenoid, we can then introduce Faraday's law, and then … no… I think, before introducing Faraday's law, we should do magnetic flux separately, as a sub-topic on its own, and then Faraday's law.*

Although the sequencing of teaching magnetic flux and Faraday's law led to the learners being confused, student NL was able to reflect critically on the teaching events and the scaffolding of concepts. As a result, her enactment of knowledge about curricular saliency was scored **rich**.

What is difficult to teach?

Student NL supported her teaching of the direction of a magnetic field around a current-carrying conductor (section 2) by using the dart analogy (referred to in theme 5 of the intervention) to help learners remember the meaning of the "dot and cross" indicating the direction of the current or field. She also reminded learners to be aware of which hand they use when applying the RHR. When teaching the magnetic field of a current-carrying loop student NL displayed knowledge of how to approach an idea that is difficult to teach. She drew two diagrams of a single loop on the board (Figure 6-12) and explained to the learners that each of the two sides of the loop can be regarded as a single wire and the RHR can be applied to each side to determine the direction of the magnetic field.

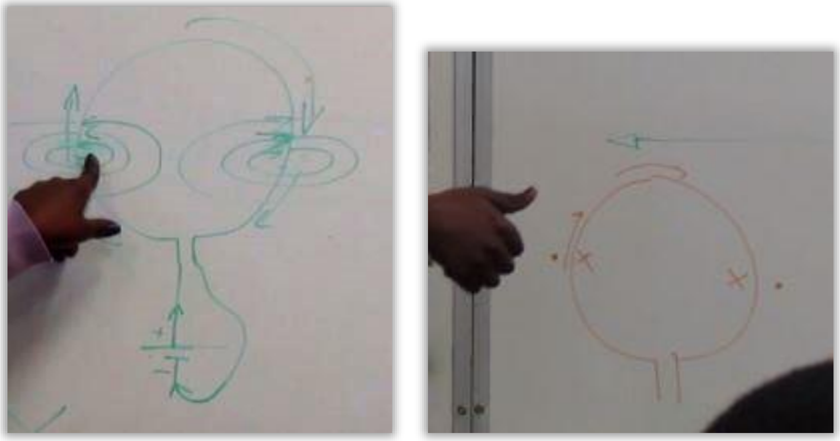


Figure 6-12: Student NL's drawings of a wire loop.

She indicated the magnetic field with field lines on the one diagram and with dots and crosses on the on the other, showing how the two diagrams corresponded. Her knowledge of how to present an idea that is difficult to teach in her first lesson was scored **rich.**

In her lesson about magnetic flux (section 5 in her lesson narrative), it was however evident that student NL was not in command of the content and struggled to teach this key idea. She did not approach the topic conceptually and relied on the repetition of the definition and the application of the equation. This topic was difficult for her to teach and she did not have a strategy to approach it. In the interview, she mentioned that she would change the sequence in which she taught the topics, but did not reflect on any other aspect of teaching this difficult concept.

> *I would change it [*the sequencing*] now. So I found it difficult for the learners to know that there's magnetic flux in the equation, but they don't know what it really is, and I had to tell them that it would be done in the next lesson, so I think I would change that if I were to do it again.*

In the section about magnetic flux, student NL worked through a problem that required the calculation of the amount of flux through a square loop that she had drawn on the board. After the calculation had been done, she asked learners to predict the direction of the induced current even though there was no reference of a change in magnetic flux. She, in fact, "fell into the trap" of the wrong phrase she herself used: "The magnetic field *flows* from north to south" – creating the impression that there is a change in magnetic flux. She even proceeded to draw the direction of the "induced current" on the diagram (Figure 6-13).

Figure 6-13: Student NL's drawing that revealed her own misunderstanding.

It is interesting to note that student NL mentioned explicitly in her post-CoRe, right after the intervention, that the magnetic flux key idea is not difficult to teach since all the information needed is available in the equation. It seems as if student NL became aware of the difficulties of understanding magnetic flux only after she attempted to teach this concept. As such, her lack of thorough understanding of the concepts proved to be detrimental to the effective teaching of these ideas and her knowledge of this component was scored **restricted**.

Learner prior knowledge

An aspect of learners' prior knowledge about magnetic fields that student NL recognised during her assessment of the knowledge of pre-concepts, is learners' confusion of electric charges and magnetic poles. She asked the question: "Where do you find a magnetic field?" and a learner replied, "Around a charge." She responded by saying: "Don't confuse magnetism with charges" and unfortunately added that magnetism has nothing to do with charge, which reveals a poor conceptual link in her mind between magnetic fields and moving charges. Later in the lesson she asked: "What does a compass do when it is in a magnetic field?" and a learner responded: "It points towards the positive of the magnetic field" to which she immediately replied: "Remember with magnets we don't have positive and negative poles." In this section of the lesson she seemed competent in her awareness of learners' thinking about the topic, even though she was not fully in command of the content yet.

In the interview, she reflected about her teaching of induced current. She acknowledged that her own misunderstanding of the existence of a magnetic field around the conductor in which current is induced might have led to poor understanding:

> *And then I kind of forgot that it also produced – the current that is being induced will also, um, have a magnetic field except the magnetic field that it was placed in, so I think the learners also had that misconception, because if they didn't, they would've picked it up when I asked them about it.*

It is evident that student NL listens attentively to the responses of her learners and is able to pick up wrong thinking. This, however, is tainted with her own compartmentalised understanding of the topic. This leads to a rating of **adequate** for her overall enactment of her knowledge of this component.

Representations:

While teaching the magnetic field around a current-carrying-conductor, student NL used both a demonstration and a diagram that she related to the setup of the demonstration (Figure 6-14). She made effective use of both these representations, using the one to support the other.

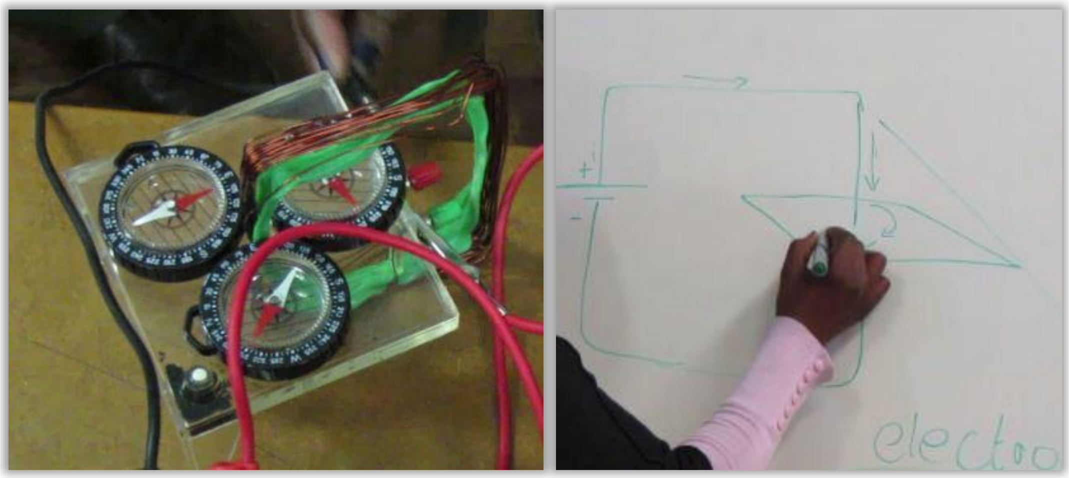


Figure 6-14: Representations used by student NL

In the VSR interview, she mentioned that she could have requested the learners to draw the pattern generated by the compasses on a piece of paper, but added that she would have preferred to use smaller compasses:

> *There should have been a drawing as well, because with the compasses, they were not perfectly making the path I showed. So if we had smaller compasses, then the results would have been clearer. Because now, some of the compasses were pointing like straight up, and probably to some of the learners that wasn't very clear. They couldn't understand how it was going around if it was pointing straight up, because they don't have the idea of tangents at this point. So longer compasses would show tangents but smaller ones would actually form a proper circle.*

For this particular section, the knowledge Student NL enacted was scored **rich,** because of her ability to implement the equipment that was available effectively and to reflect honestly and critically on her teaching.

In section 5 of her lessons, however, student NL selected representations that did not support the development of the concept of magnetic flux. She was under the impression that magnetic flux could only be explained in terms of a uniform magnetic field ("straight lines") and presented that as a reason for not using a PhET simulation as a representation:

> *The fact that magnetic field lines are not perfectly straight, right? But in the whole magnetic flux concept you're looking at a part where the magnetic field lines are straight. And then I think, same with simulations, it's more of an ideal situation, and it is one of the reasons I didn't do the simulation for this. I prefer to draw it, but … it's the fact that the lines are not straight, … and when we expand this we use straight lines. So, I find it a little bit hard to*

explain to the learners that if you take a portion of all those curved lines you find straight lines, which is what we are looking at.

Although the discussion during the intervention (see §4.2.5 p. 62-65) did not exclude curved magnetic field lines in the explanation of magnetic flux, student NL's perception did not change as a result of the intervention or could even have been reinforced by the diagram on the right-hand side of Figure 4-11 (p. 65). This perception contributed to the fact that student NL found magnetic flux difficult to teach. For this section her knowledge of the use of representations to translate the content into understandable units lacked the richness revealed in section 2 and was scored **adequate**. It appears that for a novice teacher like student NL, her competence in using representations are not on the same level even for key ideas in the same topic.

Conceptual teaching strategies

When teaching a concept with which she was comfortable, a key feature of student NL's teaching strategy was her ability to ask questions that elicited learners knowledge of pre-concepts and to listen and react to learners' responses (see lesson narrative of sections 1 and 2 in Figure 6-10). When developing the idea of the magnetic field around a current-carrying conductor, she used a demonstration and accompanying drawings effectively, and was quick to realise when learners reveal misconceptions but did not always respond in a way that would achieve conceptual change. For example, when a learner suggested that a magnetic field exists around a charge she merely said; "don't confuse magnets with charges". She did not use the statement of the learner to develop the idea that a magnetic field is not an electric field, but that a magnetic field indeed exists around moving charges. One should keep in mind that the PCK Student NL reported in her post-CoRe was not very strong. This seemed to be a typical example of "missing" wrong learner thinking by a teacher with weak declarative PCK (Alonzo & Kim, 2016). Thus, when teaching the magnetic field around a straight current-carrying conductor, student NL succeed in integrating her knowledge of the components of TSPCK as discussed in the paragraphs above. It was however not evident that she was able to attain conceptual change when required and was therefore scored **adequate**.

When teaching an idea in which she had not yet developed a sound understanding, such as magnetic flux, her enactment of the components of TSPCK also revealed a lower level of confidence (teaching sections 5 and 6). She resorted to procedural teaching by repeating the definition a few times, asking the learners to write down the relevant equation and started to do two problems where application of the equations $\phi = BAcos\theta$ and $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ was required. She seemed not a have a strategy at hand to conceptually develop the idea of magnetic flux. In the second problem, there was a particular challenge to conceptual understanding of which student NL did not take advantage. Information given in the problem stated that the magnetic flux through a coil changed from an initial value of -2.0 Wb to 1.5 Wb. In the VSR interview, she admitted that she never thought of asking learners what the meaning of negative flux may be. For her, solving the problem was about substituting the given values in the correct places.

In these sections, it was evident that she was constrained in her teaching due to her lack of conceptual understanding. This concurs with findings by Gess-Newome (1999b) and Rollnick et al. (2008). It appeared that she was not able to integrate the components of TSPCK effectively. Her poor sequencing of the key ideas led to confusion and she resorted to procedural teaching of application of formulae. Her attempted integration of learners' prior knowledge into the teaching of a new key idea led to the reinforcement of a misconception (as described under "What is difficult to teach" above). For this part of the lesson her enactment of conceptual teaching strategies was scored **restricted**.

6.2.2.2 Evidence from student NL's interview

Evidence of student NL's ability to reflect on her teaching that was not specifically linked to any of the teaching sections in her lessons, emerged from her interview and is discussed below.

Student NL's thinking about the curriculum and the content

When asked about her perceptions about her role as a science teacher after her experience during teaching practice, she responded:

> *I believe that my role as a teacher is to help learners understand concepts in science, and make sense of them. Because sometimes learners just learn about things and they don't even make sense of them. They just know that it exist, but they can't explain what those things really are, what are they used for, how do they apply in their real lives, so I think my biggest role as a teacher is to help learners understand concepts deeply and relate them to their real lives.*

This response reveals her realisation that content should be taught in such a way that learners understand the significance of what they learn. However, this conviction was not evident in the way she taught most of the concepts, which was probably a consequence of the fact that she was not comfortable with the content.

Student NL was also cognisant of the fact that the foundation for Gr 12 work is laid in Gr11 and that the Lorentz force is an important concept to be taught before learners will be able to understand the electric motor which is studied in Gr 12:

> *…the force experienced by a current-carrying wire, placed in a magnetic field. I think that should be taught a lot, because they apply it in grade twelve when they do electrodynamics. If they miss that, they won't be able to do the topic in grade twelve.*

However, Student NL did not teach this concept in the Gr 11 lessons. The impression created when comparing her interview responses and her lessons, was that student NL did not enact in her lessons all the knowledge that she declared in her interviews.

Student NL's thinking about what is difficult to teach.

Similar to student NB, student NL remembered that she found the topic of electromagnetism difficult when she herself was a learner:

> *At my high school level I remember that I thought electromagnetism was the most difficult part of physics. I think it's because I struggled with electricity a lot when I was in high school, so now when electricity was now combined with some other topics, I just had a negative attitude towards it. I thought to myself, "It's even more electricity," so the whole thing was difficult for me, from the word go.*

This perception that electromagnetism is an intimidating topic persisted when she had to teach the topic. She was apparently aware that she herself may have caused misconceptions during her teaching.

> *Overall I would say that teaching electromagnetism is very … it's not an easy thing to do. [Laughs] It's not an easy thing to do. You need to be very careful, because misconceptions are easily – like it's very easy to cause misconceptions. Yes, and it requires a lot of self-study, as well.*

6.2.3 The case of student HS

Student HS did his teaching practice at a well resourced Afrikaans high school where he taught in his first language. He taught three Gr 11 classes with 22 to 28 learners per class. Since I am fluent in Afrikaans, I have been able to analyse his lesson recordings and interviews without the help of translations. His interview was translated for the benefit of the reader (see electronic Appendix HS). The school where student HS taught was large (more than 1400 learners) and well resourced and the student had the opportunity to teach four Gr 11 classes. He mentioned that he used three or four periods to teach the topic depending on the ability of the class and the effectiveness of his teaching. Two of these lessons were observed. He used the first lesson to introduce the topic and to teach the first key idea of the magnetic field around a current-carrying conductor. He then taught a lesson on Faraday's law which was not observed. During the next lesson that was observed, he re-taught Faraday's law attempting a different sequence and approach. In these two lessons, the following sections were identified:

Section 1: (First observed lesson starts) Introducing the new topic by presenting a problem, revision of knowledge that should be in place. [5 min 40 s]

Section 2: Teaching a new key idea: *The magnetic field around a straight current-carrying conductor*. [4 min 30 s]

Section 3: Teaching a sub-ordinate idea: *The magnetic field around a loop and solenoid*. [15 min 40 s]

(A lesson about Faraday's law and magnetic flux, which was not observed or video-recorded, followed.)

Section 4: (Second observed lesson starts). Re-teaching magnetic flux. [9 min 50 s]

Section 5: Re-teaching electromagnetic induction and Faraday's law. [6 min 45 s]

Section 6: Dealing with a textbook problem on Faraday's law. [5 min 45 s]

6.2.3.1 Results from the teaching of student HS

As an example, the data collected and analysed from section 2 of student HS's lesson is presented and is followed by a discussion of the student's knowledge of the TSPCK components as enacted in the observed lessons and reflected on in the interviews. Section 2 covers the first key idea namely the *magnetic field around a straight current-carrying conductor*. Following the lesson narrative of student HS's section 2 (Figure 6-15), an Atlas.ti window showing the coding of the teaching events in this section is presented (Figure 6-16). The numbers in brackets in the lesson narrative refer to the events coded in the video clip of the lesson.

Section 2

Teaching a new key idea: *The magnetic field around a current-carrying conductor.*

[Time 4 min 30 s]

Student HS places six small compasses on a desk and draws the learners' attention to the fact that they all point in the same direction. He then places a magnet next to the compasses and asks learners to note the deflection of the needles because of the presence of a magnetic field (2.1). He also uses iron filings to show the pattern of a magnetic field of a bar magnet and emphasises that the iron filings show the pattern but not the direction and that the magnetic field is three dimensional (2.2).

Student HS then moves to the apparatus for showing the magnetic field around a current-carrying conductor (2.3). The straight wire is orientated vertically and he places one small compass one a piece of cardboard through which the straight wire runs. He moves around the compass to show learners how its orientation changes when he switches on the current. He asks learners to predict the direction of the current (2.3). They apply the RHR when determining the current. Student HS then verifies their answers by looking at the polarity of the terminals of the wire. He changes the direction of the current to show how the compass's orientation changes.

Student HS then sprinkles iron filings on the cardboard around the wire and draws learners' attention to the fact that the iron filings show the shape of the magnetic field (2.4).

Student HS presents a wire loop and tells learners that the magnetic field around the loop can be determined by looking at the loop in sections, one section taking current into the surface and one taking current out of the surface (2.5).

Figure 6-15: The lesson narrative of Section 2 of student HS

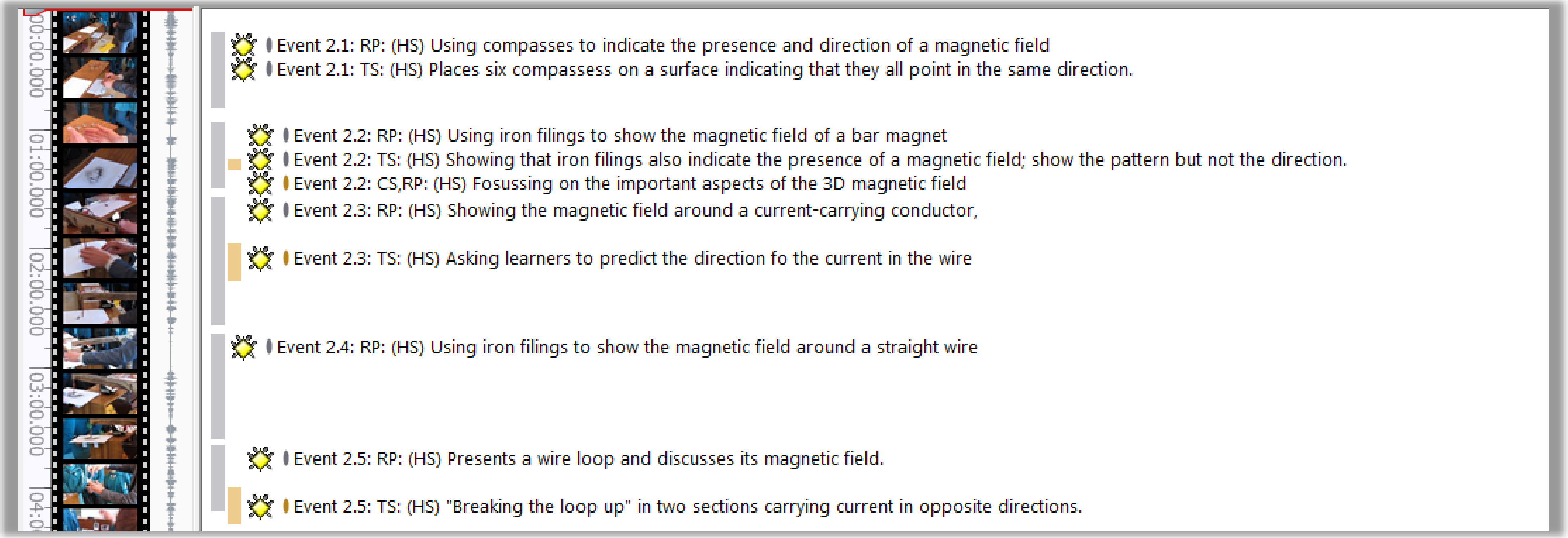


Figure 6-16: Atlas.ti window of section 2 in student HS's first lesson

Discussion of components related to the lessons taught by student HS

In the paragraphs that follow, I present evidence of student HS's enactment of the knowledge of the TSPCK components as portrayed in the lessons he taught.

Curricular saliency

Student HS had a novel way of introducing the topic in section 2 of his lessons. Unlike the other students who revised Gr 10 work through direct questioning, student HS posed a problem that learners had to solve as an introduction (see section 2 of his lesson narrative). He told learners that a person was walking with a compass in a field where there were overhead electric cables, and suddenly the compass needle deflected from its "normal north"; he asked if they could think of a reason why a compass would do that. The learners did not know the answer but realised that the reason involved magnetic fields. Only then did he ask them what they knew about magnetic fields and in this way elicited knowledge that should have been in place before the new key idea was introduced. He exhibited rich knowledge of concepts that form the foundation of the new ideas.

From evidence given in his interview, student HS attempted to teach Faraday's law and the accompanying equation before he taught magnetic flux. He realised that this sequence was not effective and upon reflection about the learners' apparent confusion, adjusted his approach (section 4 of his lessons). In the interview, he commented about his sequencing of key ideas:

> *In the first lesson, I first did the magnetic field around a current-carrying conductor. In the next lesson, I thought to do Faraday's law first and show it practically, and then do magnetic flux to explain why Faraday's law works and what happened, and then I would have gone to Lenz's law, but the learners did not understand the magnetic flux well after Faraday's law. It confused them a bit … So for the next period I presented the lesson again and changed it, and for the following classes also, first to finish magnetic flux and then proceed to Faraday's law.*

The possibility of teaching magnetic flux before the equation of Faraday is taught, was discussed during the intervention (see § 4.2.6) and this was indeed the order in which student HS presented it in his post-CoRe. Yet, when teaching, Student HS first attempted the sequencing suggested in the curriculum document (Appendix A) and only then realised the implication of teaching the concepts in a different order. Nevertheless, his ability to reflect and consider a different approach reveals his understanding of the importance of sequencing and scaffolding when teaching electromagnetism. As such, his knowledge of curricular saliency was scored **rich**.

What is difficult to teach?

In his response to this prompt in the post-CoRe, the only aspect student HS mentioned that was difficult to teach regarding Faraday's law, was the direction of the induced current. When prompted during the interview about concepts that he himself found challenging, he mentioned that he in fact did not find electromagnetism difficult:

> *I think because we have now been busy with it for a while, it was not difficult for me – because I have already done it at school and now with methodology we have also done it, so I think because it is already very well-known work, I did not experience it to be difficult.*

Yet, after his experience of teaching the topic, he admitted during the interview that teaching magnetic flux and Faraday's law was not easy. He said the learners found these concepts very abstract mostly because magnetic field lines cannot be seen:

> *I first tried to explain magnetic flux through Faraday's law, and then it was a very abstract idea for the learners, and they could not see the magnetic field lines moving through an object, then being called magnetic flux lines. Then I thought to physically represent it with lights* [laser beams]*, and then have a surface through which the lights shine like the magnetic field lines will cut through the surface.*

He used a self-constructed model (discussed under Representations) to support the teaching of these ideas, but still failed to clarify some of the aspects from which common misconceptions arise. These misconceptions include the belief that only the magnet should be moved when current is induced and that current will be induced even if the magnet is stationary inside the solenoid. The latter belief was probably caused by the impression he created that magnetic field lines move. In his explanation, he used the phrase "the magnetic field lines *cut* through the loop" without mentioning that the flux is in fact changing. Although he demonstrated that current is not induced when the magnet is kept still in the solenoid, he did not foresee the conceptual misunderstanding that arose in learners' minds. This was evident in the learner question: "Why does nothing happen when the magnet is kept still in the solenoid since there are still field lines cutting through the loop?" The question implied that the learner thought that the magnetic field lines 'cutting' through the surface was the requirement for induced current. It was evident that student HS's knowledge of this component is still developing and as a result his enactment was rated **adequate**.

Learner prior knowledge

When teaching certain key ideas, student HS planned to address common difficulties learners may have. For example in section 2 of his lesson, he mentioned that a magnetic field cannot be seen and asked learners how one can make a magnetic field visible. To support the idea he then did a demonstration with compasses and iron filings around a bar magnet (Figure 6-17). This he did as groundwork for teaching the behaviour of compasses and iron filings around a current-carrying conductor.

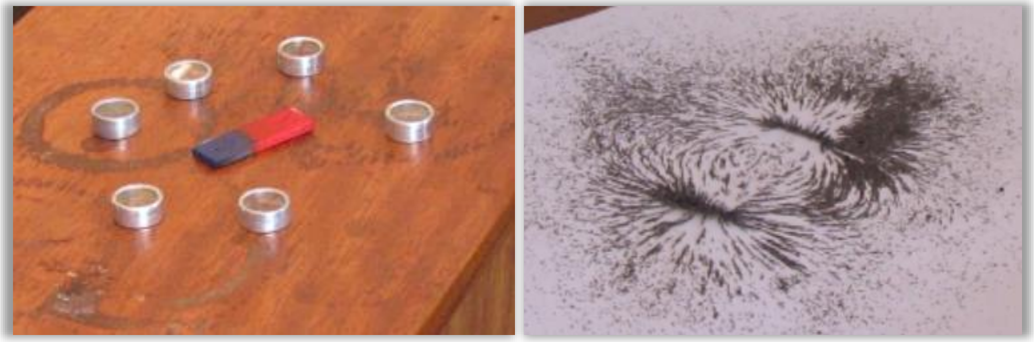


Figure 6-17: Student HS's demonstrations to support learner understanding.

In the interview he also noted a specific misconception learners had about the field of a single loop:

> *Then with the loop-shaped conductor, if one had to position poles, there was such an example in the handbook as well, then the learners wanted to put the south pole, say, where the current enters the plane and the north pole where the current exits, which is completely a misunderstanding.*

However, when evidence of learners' wrong and naïve ideas arose during the subsequent lesson (sections 5 and 6), student HS seemed to be oblivious of the reasons for such misunderstandings and did not address them. For example; after he had written Faraday's law on the board, a learner asked whether the ε stood for current and student HS merely replied that it was emf without clarifying why he had been talking about induced current and then suddenly emf appeared in the equation.

It should be kept in mind that, although student HS's TSPCK revealed in the post-CoRe was among the five highest in the class, it was not much higher than the 0,00 person location. This is an indication that student HS's reported TSPCK was not very rich. His tendency to miss learners misunderstandings concurs with a finding by Alonzo and Kim (2016) that teachers with stronger declarative PCK are more likely to recognise uncommon learner thinking.

Consequently, student HS's enactment of this component is **rich** when it forms part of his plan for a lesson and when he is confident about the content, but **restricted** when unplanned incidences occur during teaching.

Representations

Student HS made extensive use of diagrams and demonstrations to support his teaching. In the interview he made the following remark about the reason he used representations extensively:

> [It gives them] *the chance to see that it really happens, that it is not just theoretically in a book or on the board. That it can be done in reality and it can be seen and observed how it forms.*

In his first lesson, his demonstrations and accompanying use of diagrams were executed with exemplary sequencing. He started by recalling the behaviour of compasses and iron filings in a magnetic field and then used that knowledge to show that there is a magnetic field around a straight conductor and around a solenoid (Figure 6-18). The use of representations for the first lesson was scored **rich**.

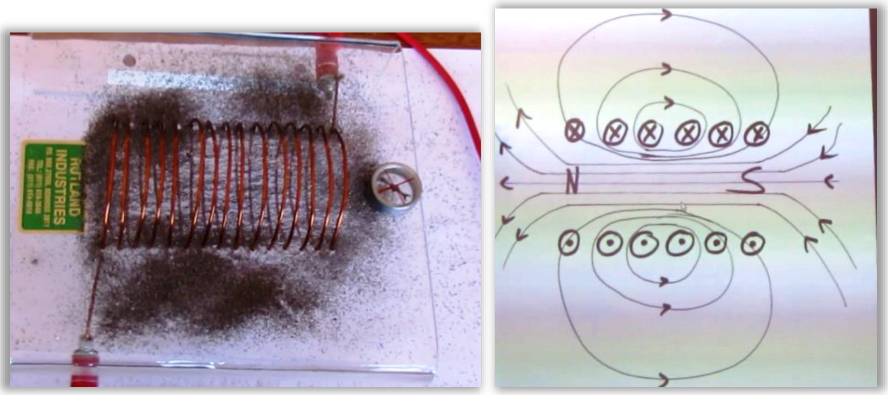


Figure 6-18: Representations used by student HS

In the second lesson he used a solenoid, magnet and galvanometer to show how current is induced and also that moving the magnet faster, induced more current and that when the magnet was kept still no current was induced (Figure 6-19); however apart from showing it, he did not elaborate and clarify the phenomenon. The demonstrations in Figures 6-18 and 6-19 were similar to demonstrations shown and discussed in the intervention.

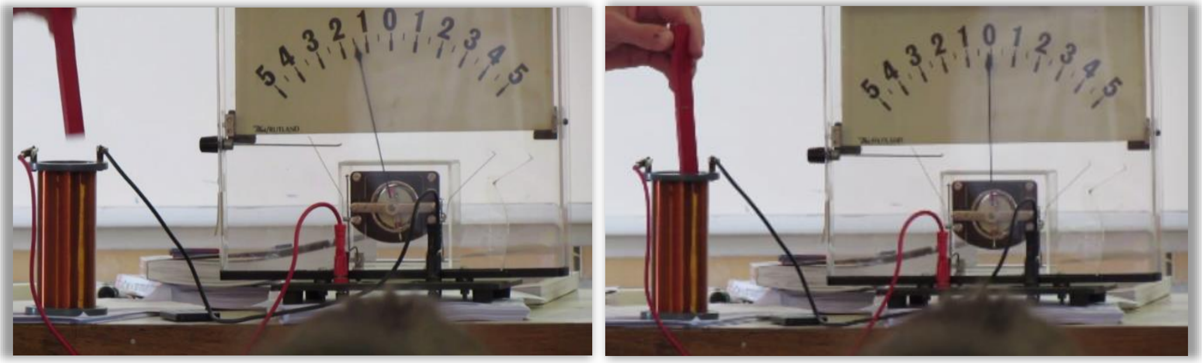


Figure 6-19: Student HS demonstrating the induction of current

When he realised that learners found the reference to magnetic flux and change in magnetic flux confusing in the lesson preceding section 4, he designed a piece of equipment to support his explanation which he used in section 4. He used two laser beams as an analogy of magnetic field lines and a transparency with black lines to represent the wires of a solenoid (Figure 6-20).

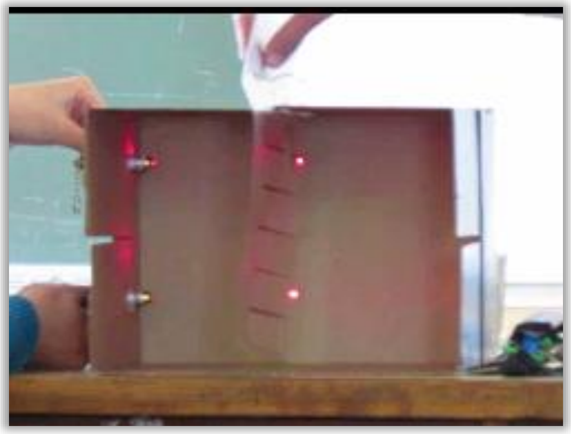


Figure 6-20: The self-constructed model used by student HS.

Moving the transparency up and down showed how the "magnetic field lines" cut through the "wires". Upon learners' confusion that in this demonstration the "wires" moved and not the "magnet", he remarked that either the solenoid or the magnet could be moved. He did not realise the full significance of this demonstration because he never mentioned the fact that the magnetic flux changes because the "transparency" moved out of the field and only talked about the “field lines cutting through the wires”. This may have contributed to the learners’ thinking that even when the magnet was stationary relative to the solenoid, current would be induced, since the magnetic field lines “cut” through the wires.

A more successful application of this model was the use of a plastic loop to show how rotation of the loop, as is often described in textbook problems, changes the magnetic flux (Figure 6-21). He used this to explain the orientation of the surface to the magnetic field, as described in the equation $\phi = BAcos\theta$.

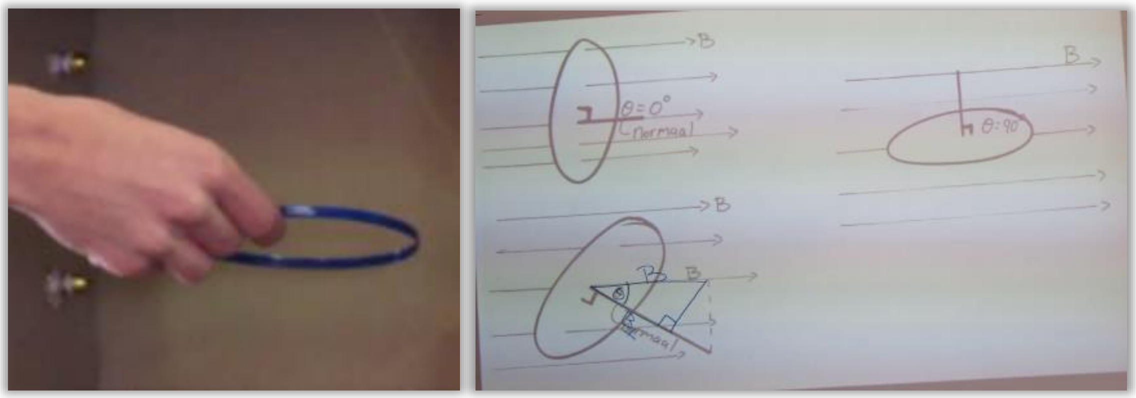


Figure 6-21: Representation used by student HS

In the VSR interview, student HS remarked the following about this demonstration:

> *And then I also used the, like a circular seal that is similar to the picture on the board, in the box, and rotated it and showed with the surface vector how it will rotate, how the angle will change.*

When he was asked what he would do to perfect his model, he responded:

> *I would put in more little lights because I had just two of the little lights available. It is a bit difficult to show the effect … like there are not just two magnetic lines that flow through it. I would like to have more of those – also, what is a bit bad is that you need a learner to help you; they must look sort of from the side or they are not going to see what is happening.”*

It was evident that this student made extensive use of demonstrations in combination with diagrams to support conceptual understanding. However, when he was unsure of the concepts underpinning the key idea, he did not use the representations to their full potential. As such his knowledge of this component in the second lesson was scored **adequate**.

Conceptual teaching strategies

In the interview, student HS remarked the following regarding his beliefs about the role of the teacher in the classroom:

> *[It] is not just transferring the knowledge to learners, but to lead them a bit more and let them see why things happen rather than just telling them 'It's true, there's a magnetic field' and by practically pointing out to them and explaining to them why some things happen, or why not.*

It seems as if student HS made an honest attempt to follow this intention. In sections 1 and 2 he combined his knowledge of sequencing of concepts and the use of representations in an attempt to support conceptual development. Through questioning and discussion he was able to integrate his knowledge of learners' ideas and representations effectively. When he was comfortable with the content, he asked questions to elicit learners' knowledge, waited for answers and used the answers to support further development of ideas. However, in later sections student HS was inclined to revert to procedural teaching especially when he was not *au fait* with the content or when he was conducting demonstrations (large parts of sections 3, 4, 5 and 6). He had a tendency to tell learners what they were observing in a "running commentary" of the demonstration and to interpret the observations for them. Student HS believed that although he was initially predisposed to procedural teaching he eventually succeeded in teaching in a mostly learner-centred manner. This coincides with the following remark by Frierichsen et al. (2009, p. 8): "Although beginning teachers described their beliefs as student-centred, they acted in teacher-centred ways."

In a discussion that prompted him to reflect on his use of direct and teacher-centred instruction, the following transpired:

Interviewer *Do you feel that that you succeeded* [in teaching learner-centred]?

Student HS: *It's difficult, one is semi-focussed on direct teaching but I think my efforts started to become easier to do this … to lead learners.*

Interviewer: *Why do you think one is focussed on direct teaching?*

Student HS: *I think at school we also mostly received direct instruction. We were not really facilitated in the learning process, and university also has direct instruction. If you do not listen to what he* [the lecturer] *says you do not know. There were not questions that lead you to the knowledge.*

This remark concurs with the finding by Eick and Reed (2002) that the pre-service teacher's learning experiences influence his beliefs about teaching.

For the first part of his first lesson, Student HS succeed in integrating different components of TSPCK as explained above and as such, the teaching strategy he employed is scored **rich**. Yet, as a result of his tendency to revert to procedural teaching, especially when teaching complicated ideas, the conceptual development of ideas was often neglected and for these sections in his lessons his knowledge of conceptual teaching strategies was scored **adequate**.

6.2.3.2 Evidence from student HS's interview

Since one of the aims of the investigation was to determine whether students use the knowledge obtained during the intervention, they were explicitly asked during the interview which sections of the intervention had been most useful to them. Student HS remarked:

> *I think the asking of the **questions**, and also the **experiments** like we saw it in the methodology class, and the way it was explained, assisted quite a bit in how I conveyed it. I tried to do it the way we did it, because I could easily understand it how it was explained to me.*

He referred to the questioning techniques that were discussed during the intervention, especially in themes 3 and 5, where students were challenged to think about the way they formulate questions to support conceptual development and critical reasoning. My impression was that student HS had greater success in implementing the knowledge gained during the intervention when he was confident with the content, but tended to fall back on the "apprenticeship of observation" (Lortie as quoted by Hargreaves, 2010) during his years as a learner, when the teaching of a topic set higher demands to his own conceptual understanding.

6.3 Summary

In this chapter, I described my search for evidence of the students' enactment of the TSPCK components that were introduced during the intervention. My pursuit was to find instances of rich enactment and integration of the TSPCK components as reflection-in-action during the lessons I observed and reflection-on-action during the interviews I conducted. I discussed the evidence from three students and elucidated my reasoning when I was scoring the levels at which the students revealed their knowledge of the components, according to a rubric I designed for this purpose (Appendix L). Table 6-4 shows a summary of levels assigned to two ideas taught by each participant.

The following ideas taught by the students are included in the table:

Student NB: The magnetic field around a current-carrying conductor (Current)
The electromagnet. (Elec. magnet)

Student NL: The magnetic field around a current-carrying conductor (Current)
Magnetic flux (Flux)

Student HS: The magnetic field around a current-carrying conductor (Current)
Magnetic flux (Flux)

Table 6-4: Summary of the scores attained by the participants

Student	Idea taught	CS	WDT	LP	RP	TS
NB	Current	Rich	--	Rich	Rich	Rich
	Elec. magnet	Rich	--	Rich	Rich	Rich
NL	Current	Rich	--	Adequate	Rich	Adequate
	Flux	Adequate	Restricted	Adequate	Adequate	Restricted
HS	Current	Rich	--	Rich	Rich	Rich
	Flux	Rich	Adequate	Restricted	Adequate	Adequate

During her lesson presentations and her reflection about her practice, student NB provided evidence that she has a rich knowledge of all TSPCK components in electromagnetism and the ability to enact this knowledge noticeably in a teaching situation. She displayed the ability to reflect critically on her actions and decisions and was aware of changes and adaptations that could be implemented to improve her teaching.

It was evident in both students HS and NL's teaching of the first key idea, that they were capable of enacting their knowledge of all the components. On the other hand, when they were not in command of the content, they resorted to procedural teaching and did not venture beyond the minimum requirements described in the curriculum document and textbooks. The demand on a teacher's sound CK is high and lack of CK has a negative impact on the quality of teaching (Rollnick et al., 2008). Furthermore, lack of knowledge of content and the curriculum may affect the student teachers' ability to differentiate between major concepts and trivial aspects and their decisions about how much time to spend teaching specific ideas (Friedrichsen et al., 2009). This was evident both in the remark of student NB that she wasted time in revising pre-concepts too thoroughly at the expense of more important ideas and the event when student NL repeated the definition of magnetic flux over and over again so that learners could write it down even when the definition was in the textbook.

In the initial CK test written before the intervention, student NL scored lowest in the class. After the intervention, her marks for the CK test improved from the initial 16.7% to 79.2%. However, this apparent improvement in CK did not overcome the barriers of her naïve ideas and misconceptions, which concurs with findings in literature. It was reported that such naïve ideas are deeply rooted and resistant to change (Gooding & Metz, 2011; Tippett, 2010) and that conceptual change can often be temporary (Duit & Treagust, 2003) as was apparently the case with student NL. This had a negative impact on her competence of integrating the TSPCK components in her teaching of difficult concepts.

However, in the interviews sessions, the students often revealed richer pedagogical reasoning and PCK than was evident in their teaching. There are two possible reasons for this: the students gained new knowledge through experience while teaching the topic and the interview was more relaxed than a teaching situation, since there was good rapport between the interviewer and the students.

Although not all three students were observed teaching Faraday' law, the outcomes of these lessons could be deduced from the interviews. As far as sequencing of concepts is concerned, all three students ventured into the teaching of Faraday's law by teaching the equation $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ first and then set out to teach the idea of magnetic flux. All three of them remarked in their interviews that they realised that learners found this approach confusing and that magnetic flux should be taught before learners are introduced to the equation. It is interesting to note that the placing of magnetic flux in the teaching sequence was discussed during the intervention. Apparently, students first had to experience the problems arising from teaching Faraday's equation before magnetic flux, before they realised the implication of the sequence proposed during the intervention. The students also remarked in their interviews that they found magnetic flux a difficult concept to teach, mostly because of its abstract nature and the fact that one cannot see magnetic field lines. This was something which that none of them mentioned in their post-CoRes. It is evident that for these three students, knowledge about what is difficult to teach was not gained from the intervention as much as from their experience of teaching the topic.

All three students made extensive use of the representations discussed during the intervention. Student HS used both diagrams and demonstrations, student NL used diagrams, demonstrations and occasionally a computer simulation, whereas student NB used both diagrams and computer simulations but was reluctant to use actual demonstrations. The fact that she was absent during the intervention session when representations were discussed and demonstrated, may have caused her self-admitted intimidation by apparatus and reluctance to do practical demonstrations. However, she demonstrated effective use of videos, simulations and diagrams combined with exemplary questioning techniques and knowledge of learner thinking. In the interview, she acknowledged the contribution the discussions during the intervention made to her knowledge of misconceptions learners have about electromagnetism. She remarked that she learned about her own misconceptions during the intervention and realised that the learners will struggle with the same misconceptions.

Remarks made by all three students alluded to the fact that their experiences as learners had an influence on the way they taught science and the instructional strategies they employed, which concurs with findings by Friedrichsen et al. (2009). This also resonates with the question posed by Grossman (1991, p. 345) and quoted in the problem statement of this study: "How can these deeply ingrained lessons from the apprenticeship of observation be challenged?" Evidence from the three students in this part of the study suggests that the challenge is indeed greater when the pre-service teacher is not in command of the content.

Although it is impossible to know how these pre-service teachers would have taught the topic had they not been exposed to the intervention (a limitation of the study), I can conclude that they implemented, although not at the same levels; the components of TSPCK as introduced to them during the intervention. *Curricular saliency* and *Representations* were the components that featured at the richest level during their teaching. With the components *What is difficult to teach* and *Learners' prior knowledge* the intervention seemed to have been less effective and the results suggested that these components had developed to a greater extent during experience in teaching the topic. As a result, *Conceptual teaching strategies* were enacted at varying levels depending on the role the other components played in a specific teaching event, and on the CK of the student. In some cases, such as teaching the magnetic field around a solenoid, the students used very similar sequencing and representations, but the teaching strategies in which they incorporated these, were not equally rich. The questions and discussions the students employed to translate the content and make it understandable to learners, also contributed to the differences in the enactment of their conceptual teaching strategies.

Chapter 7

Discussion and concluding remarks

In this chapter, I give the reader an overview of the rationale behind the study and the methodological approach. I summarise the findings of the study and explicate how these answer the research questions. Next, I make explicit the limitations to which this study was subjected. Finally, the contribution this study makes to the body of knowledge about the development of TSPCK of pre-service teachers is highlighted together with recommendations on similar and further studies.

7.1 Overview of the study

The overarching purpose of the study was to determine to what extent the knowledge and experience student teachers gained during their final year of study contributed to the development of their PCK about electromagnetism.

In the introduction to this study, I referred to the special knowledge base teachers should possess and how that differs from the knowledge possessed by the subject specialist. Teachers need to be able to transform their subject knowledge successfully to make it understandable to learners in situations where they have to deal with different amounts of resources and diverse abilities of learners. This requires a particular kind of knowledge that is unique to a teacher. The construct of Pedagogical Content Knowledge (PCK) offers the possibility of linking the different knowledge bases of content and pedagogy as proposed by Shulman (1986, 1987). It was reasonable to assume that the groundwork for obtaining this knowledge should be done in pre-service teacher education in accordance with suggestions by Friedrichsen et al. (2009). This also resonates with the concern Mavhunga (2014, p. 31) raises: "In the absence of a nationally coordinated PCK-oriented teacher induction programme for beginning teachers, both conditions for acquisition of PCK (adequate content knowledge and experience) are unlikely to be met."

Consequently, I aimed my study at the period of training in the final year of physical science teacher students that involved coursework and teaching practice at schools. As a science teacher educator I was interested in establishing whether and to what extent the training they received during their methodology module was useful, in the sense that they could incorporate their new knowledge into their teaching. Thus, I refined an existing subject methodology course as an intervention included in the training of pre-service science teachers with the aim of cultivating an understanding of the knowledge bases that made up their PCK as well as the ability to apply this knowledge in practice.

To investigate the development of pre-service teachers' PCK, I formulated the following research questions:

- How is the development of the PCK of pre-service teachers influenced by the explicit inclusion of TSPCK about electromagnetism in pre-service teacher education?

Sub-questions:

1. What is the impact of an intervention, focussing on the components of TSPCK, on the level of CK and PCK of pre-service teachers in electromagnetism?

2. To what extent is PCK learned during the intervention, manifested in the practice of pre-service teachers as revealed during Teaching Practice?

The decision to use the topic of electromagnetism as a vehicle to translate the knowledge of the TSPCK components for student teachers stems from evidence in literature (Dori & Belcher, 2005; Sağlam & Millar, 2006) that this topic causes many misconceptions and that learners find it challenging. Thus, teaching electromagnetism necessitates a unique pedagogy and a firm understanding of the topic. Since electromagnetism is notoriously difficult both to understand and to teach, the topic provided a unique opportunity to investigate the link between CK and PCK.

Figure 7-1 shows how different aspects of the study and the instruments are linked to the conceptual framework explained in § 2.4. The framework shows how the personal PCK of a teacher is initially developed through training, based on the canonical PCK that belongs to the profession and established by research and the contribution of experts. This conceptual framework resonates well with the latest Refined Consensus Model (RCM) for PCK (Carlson & Daehler, in press) which will be discussed in § 7.6. In this study the canonical PCK is represented in the expert CoRe about electromagnetism Gr 11 (Appendix H), constructed for this study by experienced science teachers and teacher educators. Each of the prompts in the CoRe can be associated with one of the components of TSPCK, which in this study was considered the essence of the canonical PCK that informed the intervention (Appendix C). The intervention was conducted during the first term of the final year of the pre-service teachers' study. The contribution of the intervention to the development of the student teachers' personal PCK about electromagnetism was explored through the pre- and post-CK tests and CoRes written by the participants. This answered the first sub-question.

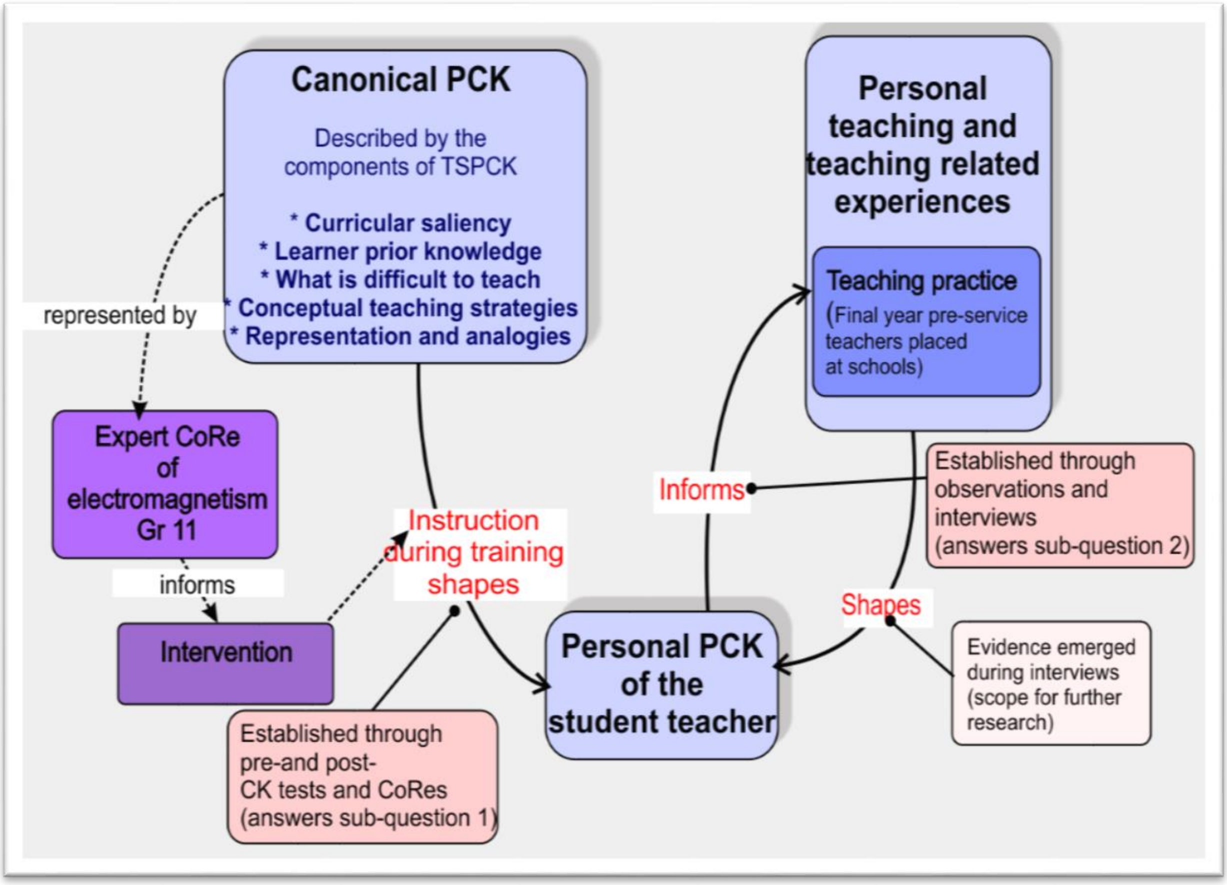


Figure 7-1: Diagram representing the link between the conceptual framework and the research design.

The first formal opportunity the student teachers had to enact their personal PCK was during their terms of teaching practice when they were placed at schools. During this time, I observed and video recorded at least 60 minutes of electromagnetism teaching by each of three students who also participated in the intervention. I conducted VSR and semi- structured interviews with these three students to elicit their thinking about their lessons and electromagnetism teaching in general. I scrutinized their lessons and interviews for evidence of the enactment of their personal PCK and whether it could be linked to aspects taught during the intervention, answering sub-question two. I found evidence that their teaching experience shaped their PCK in aspects that the intervention did not.

7.2 Discussion of the findings

Data collected during the course of the intervention included my personal reflective journal (Appendix D) and the students' mid-intervention CoRes. These enabled me to establish certain features of the thinking of pre-service teachers about teacher knowledge. It was evident that, at the start of the intervention, the group of final-year student teachers who participated in the study, saw themselves as "expert students" rather than "novice teachers" (Shulman, 1986, p. 8). At the time of the study the participants had all completed between one and three years of undergraduate Physics. A typical aspect of student thinking that became evident was their perception that content knowledge was something they should possess rather than something that needed to be translated into understandable units during teaching. They also thought about knowledge and competence for teaching merely in broad pedagogical terms, such as maintaining discipline, presentation skills and operating technology effectively and not in terms of the aspects referred to by the five components of TSPCK (see § 4.2.1 p.56). These perceptions seemed to have been resistant to change, despite being addressed during the intervention. The inability of the student teachers, after three years of training at a university, to think about science content as something to be taught and about themselves as the agent through which the translation of content should take place, attests to the concern raised by Grossmann, Hammerness and McDonald (2009) concerning the divide between content courses and methodology.

The second phase of the study entailed the observation of three students during their teaching practice when they taught electromagnetism. In the paragraphs to follow, the impact of the intervention in terms of the student teachers' development of CK and TSPCK and their ability to enact their attained PCK about electromagnetism will unfold.

7.2.1 Impact of the intervention on student teachers' content knowledge

The 14 student teachers who participated in the intervention were final-year BEd students who had completed at least one year of undergraduate Physics (Table 5-2 p.75). At the start of the intervention they wrote a CK test about electromagnetism concepts related to the Gr 11 curriculum (see Appendix A) and repeated the test at the end of the intervention. As explained earlier, content was not explicitly taught during the intervention, but electromagnetism was used as a vehicle to teach TSPCK by focussing on the components in the framework of the study. Nevertheless, since the development of

CK is reported to be connected to the development of ideas for teaching the content (Rollnick, 2017; Rollnick & Davidowitz, 2015), it was considered worthwhile to investigate the impact of the intervention on both CK and TSPCK.

An interesting finding was that the level at which the participants completed undergraduate physics was not a predictor of their performance in either the pre- or post-CK test (see Table 5-2). For example, there were four students in the sample who had completed Physics at third-year level, but two of them were among the lowest performers in both CK-tests.

A Rasch analysis of CK test results was done using the RUMM 2030 software. The validity of the test in terms of overall fit to the Rasch model, response independence and unidimensionality was established. The overall performance in the CK test improved from an average of 36.2% in the pre-test to 67.4% in the post-test, including three students whose performance did not improve. The lowest class attendance was recorded for these students, which in an inverted sense, points to the positive effect the intervention had on development of CK.

The level of difficulty of the items as perceived by the participants before and after the intervention was established by racking the data (see § 5.2.4 p.79), that is, by placing the pre- and post-test on the same linear scale. The item map for the racked data showed that the students perceived all the items as easier in the post-test except items 5, 6 and 8. These items required the integration of knowledge about more than one concept and critical reasoning. This suggests that the intervention, which was focussed on the development of TSPCK, did not have the development of critical reasoning about content as an outcome, even though basic CK improved.

Stacking the data for Rasch analysis means considering the sample as two separate groups for the pre- and post-tests placing them along the same continuum in order to compare them to themselves before and after the intervention. The technique of stacking the Rasch data suggested that the intervention had a more pronounced impact on the development of students with higher ability. The three students who participated in the second phase of the study were among the top four performers in the post CK-test. This was not intentional, but an outcome of pragmatic sampling. However, they all remarked later, in their interviews, that they found electromagnetism in general and Faraday's law in particular a very difficult idea to teach and that they were not comfortable with the content. It was evident that knowing the content for teaching required a different knowledge base than knowing the content for answering questions in a multiple-choice CK test. This resonates with Shulman's idea of PCK which was confirmed by authors such as Gess-Newsome (1999b) and Rollnick (2017).

7.2.2 Development of PCK about electromagnetism

The development of PCK was measured by a version of the CoRe tool modified by Rollnick and Mavhunga (2016) to include the components of TSPCK explicitly (Figure 2-2 p.20). Participants constructed a pre-CoRe before the start and a post-Core after completion of the intervention. An expert CoRe for electromagnetism Gr 11 (Appendix H), constructed by me, two experienced physical science teachers and a science teacher educator, represented the canonical PCK (see § 2.4) about the topic, and was used as a yardstick against which the participants' CoRes were gauged. A CoRe-rubric (Appendix G) was designed to score the responses of the participants in order to quantify their TSPCK for the purpose of the Rasch-analysis. Descriptive and numeric levels of limited (1), basic (2), developing (3) and exemplary (4), were assigned to each response. Level descriptors that clearly distinguished between the four levels of knowledge about the different components of TSPCK had to be formulated. Discussing the level descriptors with co-scorers and implementing a Rasch analysis enabled me to refine the rubric. When the level descriptors for a specific prompt did not clearly distinguish between levels, Rasch analysis flagged reversed or disordered thresholds, discussed in § 5.3.2. The existence of disordered thresholds may have resulted in a more able student obtaining a lower score than a less able student for the particular prompt. This feature enabled me to identify descriptors that had to be refined. Finally, I established that the instrument, the rubric and the sample fitted the Rasch model and the outcome of the Rasch analysis could be interpreted.

After refinement of the rubric the Rasch analysis showed that there was a statistically significant improvement in the TSPCK of the participants as measured by the CoRe tool (§ 5.3.3 p.95). The finding that both CK and TSPCK developed during the intervention supported the notion expressed by Mavhunga (2014) that CK is not necessarily a *precursor* for PCK and that these two can develop simultaneously. Furthermore, the findings in the current study concur with other suggestions in literature (Davidowitz & Potgieter, 2016) that although good CK is a necessary component of quality PCK about a topic, it is not sufficient, since not all participants with improved CK revealed improved PCK. Furthermore, for this particular sample, none of the students with poor CK displayed quality PCK. In the discussion that follows, I often allude to evidence from the study that knowing and understanding more about electromagnetism, as revealed in an improved score in the post-CK test, did not automatically imply an increased ability to think about the topic in terms of teaching.

The first section in the CoRe revealed knowledge about *Curricular saliency* (prompts A0 – A4). Figure 5-22 (p. 100) shows that knowledge about the selection of key ideas and the identification of sub-ordinate ideas related to the key idea improved considerably. These two aspects were discussed during the intervention and students were able to incorporate the new knowledge into their PCK, as revealed in the post-CoRes. Four students selected magnetic flux as a key idea in the pre-CoRe and nine in the post-CoRe (see Table 5-6). The awareness of the importance of magnetic flux may be ascribed to the fact that a discussion took place during the intervention about the sequencing of Faraday's law and magnetic flux in the curriculum (CAPS). The curriculum does not introduce magnetic flux explicitly as a pre-concept for the understanding of Faraday's law. During the intervention discussion students agreed that magnetic flux should be taught as a key idea before an attempt was made to teach Faraday's law and its associated equation. This was, in fact, the sequence that all three students who participated in the second part of the study, suggested in their post-CoRe.

The improvement in knowledge about the component *What is difficult to teach* was minimal, with nine students scoring the same or lower in the post-CoRe than in the pre-CoRe. The responses related to this component revealed that students' answers originated from their own perceptions about the difficulty of the concepts. This is reasonable, since they had never taught the topic before and had no experience of what learners normally find difficult to understand. A typical example was student NL who wrote in her post-CoRe that nothing was difficult to teach about magnetic flux. Yet, in her interview after teaching the concept, she remarked that she found the concept extremely difficult to teach.

Typical and well-documented misconceptions about magnetism and electromagnetism were discussed during the intervention. This resulted in improved responses to the CoRe-prompt (C1) that required students to declare their knowledge about *Learners' prior* *knowledge*. Despite the slight improvement in knowledge about learners' thinking as seen in the Post-CoRe, this prompt remained one of the lowest items on the Rasch item map after the intervention. Their responses originated not so much from their knowledge about learners' thinking as from a realisation and memory of their own misunderstandings. Students NB and NL confirmed this in their interviews when they said that they did not understand this topic when they were learners and that they based their knowledge of learner thinking on what they themselves found difficult.

The improvement in knowledge about *Representations* that can be used in teaching electromagnetism was apparent in the students' responses to the post-CoRe prompt E1. Seven students were scored limited in the pre-CoRe and only two revealed knowledge at this level in the post-CoRe. In contrast to their responses in the pre-Core, students referred to specific equipment in the post-CoRe such as magnets, straight conductors and solenoids, and also to specific simulations that can be used. This component was discussed extensively during the intervention, where participants were exposed to the implementation of demonstrations, simulations and diagrams when teaching electromagnetism, which may account for the improved responses.

When prompted to articulate a *Conceptual teaching strategy* for a particular key idea, students had to show their ability to integrate the other components into a coherent approach to attain conceptual development. There was improvement in knowledge shown by the responses to this prompt (D1), since students realised that merely mentioning a teaching method such as direct teaching or inquiry-based teaching, does not reveal their knowledge of a conceptual approach to teach a key idea. However, not all the students grasped the necessity of incorporating their knowledge of the other components into a teaching strategy. In prompt D2 the students reported on the questions that could be asked while teaching a specific key idea. Since this aspect was an important focus in the intervention, the post-CoRes showed much improvement in the responses to this prompt. It seemed, however, that students did not consider the relation between the questions they asked and their teaching strategy.

7.2.3 Enactment of PCK about electromagnetism

For the three students involved in the second phase of the study I investigated the extent to which they were enacting their knowledge of the components of TSPCK taught during the intervention. Analysis of the lesson video-recordings gave evidence of their ability to enact their PCK, while the interviews conducted after their teaching experience enabled me to elicit their pedagogical reasoning about their teaching. The extent to which the students were enacting their PCK was not the same for the three students; neither was it the same over all key ideas.

A three-category lesson rubric was designed and used to assign levels of enactment for the five TSPCK components (Appendix L). Remarks made during interviews that revealed reasoning about their teaching were also taken into account when scoring the enacted PCK. It is noteworthy that the two components that emerged as the ones enacted at the highest level were the ones that were presented at the highest level in the CoRe tool, namely *Curricular Saliency* and *Representations.* Surprisingly, the three phase-two participants did not teach magnetic flux and Faraday's law in the sequence they presented in their post-CoRes. In their lessons, all three attempted to teach Faraday's law first. Reasons for this decision was not given, but they commented in their interviews that it was very inefficient and that magnetic flux should rather be taught explicitly before Faraday's law. In this case, experience convinced them of the significance of the discussion that took place during the intervention.

Enactment of the components *What is difficult to teach* and *Learner prior knowledge* lacked richness in the lessons of students HS and NL. Both these students missed opportunities to correct learners' wrong thinking about magnetic flux and unintentionally reinforced the misconception that the mere existence of magnetic flux will induce current in a solenoid. Student NL, whose performance in the CK test improved from 17% to 79%, and student HS who improved from 37% to 91%, had deeply rooted misconceptions that became visible during their teaching. Although the misconceptions were resistant to change during the intervention, student NL remarked in her interview that she became cognisant of the misconceptions while reflecting upon her teaching. The participants displayed richer reasoning about *What is difficult to teach*, *Learner's prior knowledge*, and *Conceptual teaching strategies* during the interview after their teaching experience, than had been revealed during their actual teaching. This supports the importance of experience in learning to teach, described by Lampert as quoted by Grossman et al. (2009, p. 275):

> *Because teaching is situated in instructional interaction, learning how to teach requires getting into relationships with learners to enable their study of content. It is here that one learns how to teach as students 'act back' and responses must be tailored to their actions.*

In this study, it was evident that when participants were in command of the content they were able to integrate the components of TSPCK effectively into their *Conceptual teaching strategies*. Evidence that students' CK about *magnetic field around a current–carrying conductor* improved, is found in the increase in correct responses to items 1 and 2 of the CK test (see Figure 5-9 p.82). Being comfortable with the content of this key idea, the students displayed confidence when teaching the concept. They asked questions to probe learners' understanding, used several representations to support the translation of the concepts and scaffolded the teaching of new ideas effectively. Although their teaching approach was mostly teacher-centred, they managed to involve learners through questioning and teacher-learner dialogue.

A typical example is Student NL who incorporated the use of a representation, her knowledge of learner thinking and effective questioning when teaching *the magnetic field around a current-carrying wire*. Yet, when teaching *magnetic flux*, which she acknowledged in the interview was a difficult topic, she showed little awareness of typical misinterpretations and did not ask questions that led to conceptual development, showing ineffective integration of the TSPCK components.

When students were not in command of the content, as was the case with *magnetic flux*, they did not venture beyond the minimum requirements of the curriculum and employed procedural teaching by repeating definitions and explaining how to substitute values into equations. All three students remarked in their interviews that they found magnetic flux a difficult concept to teach. The findings suggest that when students are not comfortable with the content, they do not integrate the components of TSPCK effectively and their instructional strategies seemed to collapse. This concurs with the views of Mavhunga (2018), who considers teaching sequences where a number of components interact as "reflecting sophisticated TSPCK" (p. 10).

7.3 Answering the research questions

In answer to sub-question one, the findings of this study indicated that an intervention focussing on the five components of TSPCK about the topic of electromagnetism improved both the CK and the PCK about electromagnetism of the participating students.

The CK of the participants about the topic improved significantly with an ANOVA p-value of 0.0043. Neither the pre-CK test nor the content was explicitly discussed during the intervention and the group of participants had no other collective exposure to the topic. I therefore consider it a fair conclusion that the students' knowledge of the topic improved as a result of the intervention. Furthermore, there was a larger separation between the low- and high-performing students in the post-test than in the pre-test (see Figure 5-6 p.80), which is an indication that the more able students benefitted to a larger extent from the intervention than the less able students. Findings suggest that some of the misconceptions students had did not change permanently as a result of the intervention but recurred when the students were teaching the topic during the second phase of the study.

The PCK about teaching electromagnetism as measured with the CoRe tool showed a significant improvement, with an ANOVA p-value of 0.0081. It was first of all evident that, although the participants were all pre-service teachers with more or less the same level of experience, they did not reveal the same level of PCK (see figure 5-20, p.98). The largest improvement was in responses given to the prompts eliciting knowledge about *Curriculum saliency* (A0, A1 and A2) and *Representations* (E1), whereas *What is difficult to teach* (B1) and *Learners' prior knowledge* (C1) proved to be challenging to students, even after the intervention. As a reminder and for the convenience of the reader the comparison of the pre- and post-CoRe, Figure 5-22 is repeated here as Figure 7-2.

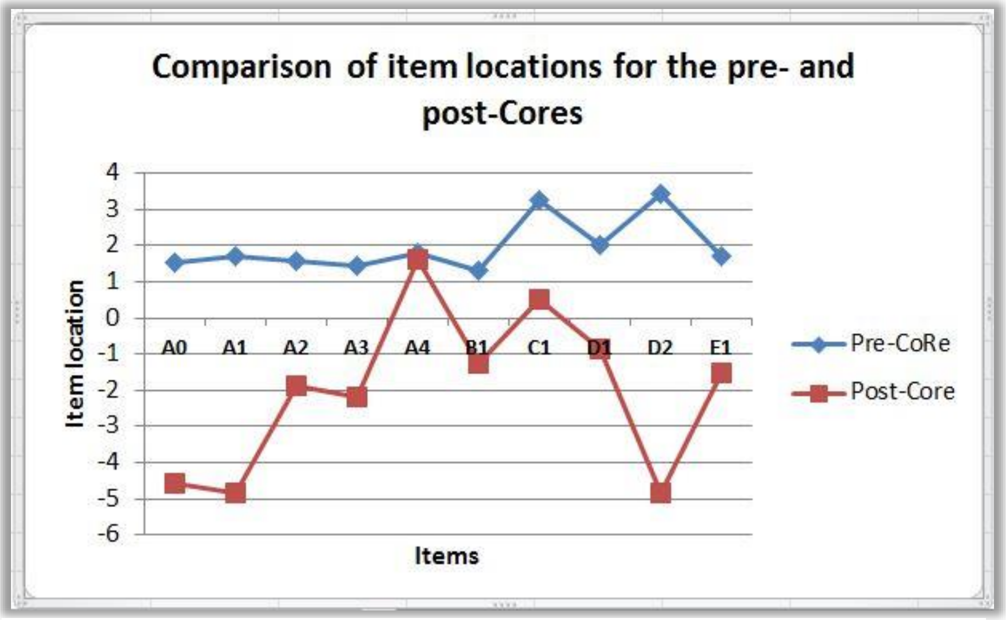


Figure 7-2: Comparison of pre-and post-CoRe item locations

Since not all the components of TSPCK developed to the same extent during the intervention, the students' pedagogical reasoning towards planning *Conceptual teaching strategies* seemed to have been restricted. The prompt that required students to describe their planned instructional strategies (D1), scored third lowest in the post-CoRe. This supports the importance of the integration of the different components into PCK, which in the words of Park and Chen (2012, p. 923) is "critical to PCK development" and "enables a teacher to transform content knowledge into instructional events from a more holistic perspective".

To establish whether student teachers were able to enact the knowledge attained during the intervention, as formulated in research question two, I analysed the lesson video recordings and interviews. In the semi-structured and VSR interviews, participants had the opportunity to reflect on their teaching and to elaborate on their pedagogical reasoning while teaching electromagnetism concepts. This gave me the opportunity to triangulate the findings that originated from the observations.

Although it is impossible to know how these pre-service teachers would have taught the topic had they not been exposed to the intervention (a limitation of the study), I can conclude that they were able to enact the components of TSPCK explicitly discussed during the intervention, even though they did not enact all the components at the same level. Despite the problems the students experienced with the sequencing of certain concepts, they were able to acknowledge and reason about the implications and realized that they should change their approach, revealing a rich understanding of the *Curricular saliency* of the topic. *Representations* was another component that featured at a high level during the students teaching of electromagnetism. They benefitted from the session during the intervention when demonstrations and simulations were discussed. During the intervention phase, many students remarked that they have never seen such representations before. For the components *What is difficult to teach* and *Learners' prior knowledge,* the intervention seemed to have been less effective and the results suggested that these components developed during experience in teaching the topic.

Rich enactment of *Conceptual teaching strategies* becomes visible when the other components interact effectively. As such, this component was enacted by the students at varying levels, depending on the role the other components played in a specific teaching event and on the CK of the student. In some cases, such as teaching the magnetic field around a solenoid, the students used similar sequencing and representations, but the teaching strategies in which they incorporated these, were not equally rich. The teacher-learner dialogue employed by the students to translate the content contributed to the differences in the enactment of their conceptual teaching strategies.

In conclusion, it was found in this study that the training of the pre-service teachers in their fourth year of study, contributed significantly to the development their PCK, where *training* in this sense involved the intervention that took place during a methodology course and their formal supervised teaching practice. Concurring with findings by Toerien (2017), this study suggests that not all TSPCK components developed to the same extent and that teaching experience will support the improvement of knowledge about learner thinking and the design of conceptual teaching strategies.

7.4 Emerging findings

Apart from the answers to the research questions, several other findings emerged during analysis of the data and are discussed below.

Teacher-centred teaching does not necessarily reflect poor PCK

The student teachers believed that their teaching approaches were learner-centred, but their observed practices proved to be teacher-centred, especially when they were not in command of the content. This coincides with the findings of Mansour (2013), who found, in a study on teachers in Egyptian schools, that there are often inconsistencies between teachers beliefs and practices. Some teachers who believed that they had a reformed, constructivist approach, often taught in a traditional way, showing that their beliefs did not always translate into practice. However, one cannot conclude that poor PCK should necessarily be associated with traditional teacher-centred strategies. In this study, all three students whose lessons were analysed revealed rich PCK when teaching a concept they understood well. Even though their approaches when teaching electromagnetism was mostly teacher-centred, they used multiple representations presented with exemplary sequencing supported by effective questioning, involving learners and guiding them towards conceptual understanding. This supports a finding by Mavhunga and Rollnick that "when considering PCK at a topic level, caution should be exercised against presenting teacher-centred practices in science as automatically likely to reflect poor PCK" (2016, p. 852).

Sequencing of concepts in electromagnetism Grade11

The students who took part in the second phase of the study reported afterwards that they attempted teaching Faraday's law without explicitly teaching the idea of magnetic flux first, even though a reversed order was agreed upon during the intervention. All three students remarked that they struggled to teach Faraday's law because the learners had to grasp the idea of magnetic flux, the change in magnetic flux and its link with induced current all at once. They all conceded that they had learned from experience that the idea of magnetic flux should be taught before Faraday's law. This finding leads to a suggestion that is laid at the feet of school science curriculum developers in South Africa. Consideration should be given to the explicit inclusion of magnetic flux in the curriculum as a concept that should be taught before Faraday's law.

Poor verbalisation in "science language" by student teachers

Students sometimes use inappropriate prepositions and verbs that cast doubt on their own understanding of the content and if used in teaching may eventually lead to incorrect understanding by the learners. For example, one student wrote in a CoRe, "A magnetic field exists *in* a current-carrying conductor" instead of *around* a current-carrying conductor. It is not clear whether the student's own perception of the magnetic field is correct and which understanding she will convey to learners.

They also inadvertently confused themselves and their learners by using inappropriate words to describe a magnetic field. This misconception, connected with the perception that magnetic field lines indicate "flow", was described by Sağlam and Millar (2006). In constructing the CoRe one of the students wrote: "the magnetic field is *going* from north to south" and both students NL and HS used phrases in their lessons such as "the magnetic field lines *flow* or *move* from north to south", suggesting that the magnetic field moves. This could engender thinking in the learners that the magnetic field itself can go somewhere, which has serious implications for the understanding of the change in magnetic flux. When explaining the induction of current by moving a magnet in and out of a solenoid, the student teachers focussed on the motion of the magnet and failed to emphasise the importance of the change in magnetic flux. Learners then tend to believe that the *motion* necessary to induce current is in fact the *motion* or *flow* of the magnetic field. These misunderstandings resulting from poor verbalisation probably contributed to the conclusion of the student teachers that magnetic flux and Faraday's law were difficult concepts to teach.

7.5 Limitations and delimitations of the study

The results of the study should not be generalised to the broad population of pre-service physical science teachers. The study was conducted with a group of students that was diverse in terms of gender, race and primary language, but they were all studying in the Faculty of Education of the same university. Furthermore, the sample for the case study in the second part of the study consisted of only three students, albeit diverse in terms of gender, primary language and race. The study does, however, complement the work of researchers such as Abell et al. (2009), Kind (2009), Brown et al. (2013), Rollnick and Mavhunga (2016) and Gess-Newsome (2015) and contributes to theory about the development of TSPCK of pre-service teachers.

Other aspects that could be regarded as limitations should be kept in mind when interpreting the findings of the study:

- Considering the nature of the construct TSPCK, it is expected that a teacher's PCK may not be the same from topic to topic. In addition, it was found in this study that pre-service teachers' TSPCK was not even the same over different key ideas in the same topic. As explained in the discussion of findings, it was clear that participants generally revealed, in both the TSPCK reported in the CoRes and the enacted TSPCK, a higher level of competence in the key idea *magnetic field around a current-carrying conductor* than in *Faradays' law*. However, when scoring the CoRes, the score assigned was for the key idea that revealed the highest level of knowledge and was considered the level of knowledge for that component over all key ideas. Therefore, when an improvement in TSPCK was indicated for a particular student, the improvement may not have been across all key ideas. As such, analysing the CoRes both quantitatively and qualitatively resulted in a richer picture of the effect of the intervention on the TSPCK the students declared in their CoRes. This aspect points to the necessity of taking into consideration the grain size (Carlson & Daehler, in press) of the content accessed in a teacher's PCK.
- The instrument I used to measure the CK of the participants was a test with multiple-choice items in which the score indicated the level of the CK of the participant. During the study, I encountered instances where students'

performance in the CK test improved greatly, but they revealed in their teaching that they harboured deeply rooted misconceptions. These misconceptions were not exposed in the CK test. This observation is in accordance with Luneta and Makonye (2010), who mentioned that misconceptions can be obscured by correct answers. A suggestion for similar future studies would be to require participants to give reasons for their answers in each item. This would enable the researcher to identify misconceptions that may exist despite correct answers in the multiple-choice items and could inform teacher educators about misconceptions that should explicitly be addressed during training when discussing *Learners' prior knowledge.*

- Logistical aspects enforced the limitation on the study mentioned in Chapter 6. In order to answer sub-question two I needed to establish whether the students were able to enact their newly attained PCK during teaching. However, there was no opportunity to obtain an indication of the baseline dynamic PCK of the participants. The students did not have access to schools in the first term of the year and the dynamic PCK of the students could not be accessed before the start of the intervention. Hence, I could not assume that the aspects of their PCK about electromagnetism that became evident during the lesson presentations necessarily resulted from knowledge gained during the intervention. As such, I could not claim that the enacted knowledge observed during lessons was the result of the intervention. I could merely report on obvious links and similarities between issues discussed in the intervention and knowledge revealed during teaching.
- Limitations related to observer effects and personal bias, including observational bias, the halo and Hawthorne effects, are discussed in detail in the introduction to Chapter 6.

Through a full description of the methodology of this study, a rich narrative about the qualitative data, a clear explanation of the validation of the quantitative data and an upfront declaration of the limitations, the reader is afforded the opportunity to audit the method and the findings and come to a conclusion about the trustworthiness of the findings of this study.

7.6 Contribution of the study

This study contributed to the body of knowledge about the development of the TSPCK of pre-service teachers. The findings not only contributed to the theory of PCK development but also offered an innovative way to analyse pre- and post-assessments by the stacking of Rasch data .

Contributions related to findings

The exploration of the TSPCK about electromagnetism - a topic that has not been investigated before in terms of the development of the PCK of pre-service teachers, is an important contribution of the study. The study explicitly focussed on how the knowledge to which student teachers were exposed during the intervention became part of their personal PCK and to what extent they were able to implement this in classroom practice. The study showed that not all the components of TSPCK developed to the same level, with knowledge about learner thinking and teaching strategies at the lower end of the scale. This may guide teacher educators in the development of methodology courses in which student teachers are supported to expand their knowledge about these components in different curriculum topics.

The conceptual framework, paying specific attention to the positioning of the canonical PCK, personal PCK of the teacher and the classroom practice, proved to be valuable in the design of the study and the organisation of the results and findings. The aforementioned aspects of the conceptual framework of this study coincides with the RCM (Carlson & Daehler, in press) (see Figure 7-3, p.182). The collective PCK (cPCK) is knowledge that is shared between professionals and builds on canonical PCK. It may be appropriate to replace the term canonical PCK in the framework of the current study with cPCK, since the expert CoRe that represents the canonical PCK in this study was a contribution from experts in the field. The personal PCK (pPCK) is a “reservoir of knowledge and skills that the teacher can draw upon during the practice of teaching” (Carlson & Daehler, in press, p. 9), and is shaped through formal education as is indicated in the conceptual framework of this study . Enacted PCK (ePCK) of the RCM links to personal teaching and teaching-related experiences of the conceptual framework, and as acknowledged by the RCM, is informed by and shapes the pPCK. The findings of my study indicates that the RCM is a fruitful description of PCK in the context of pre-service science teacher education.

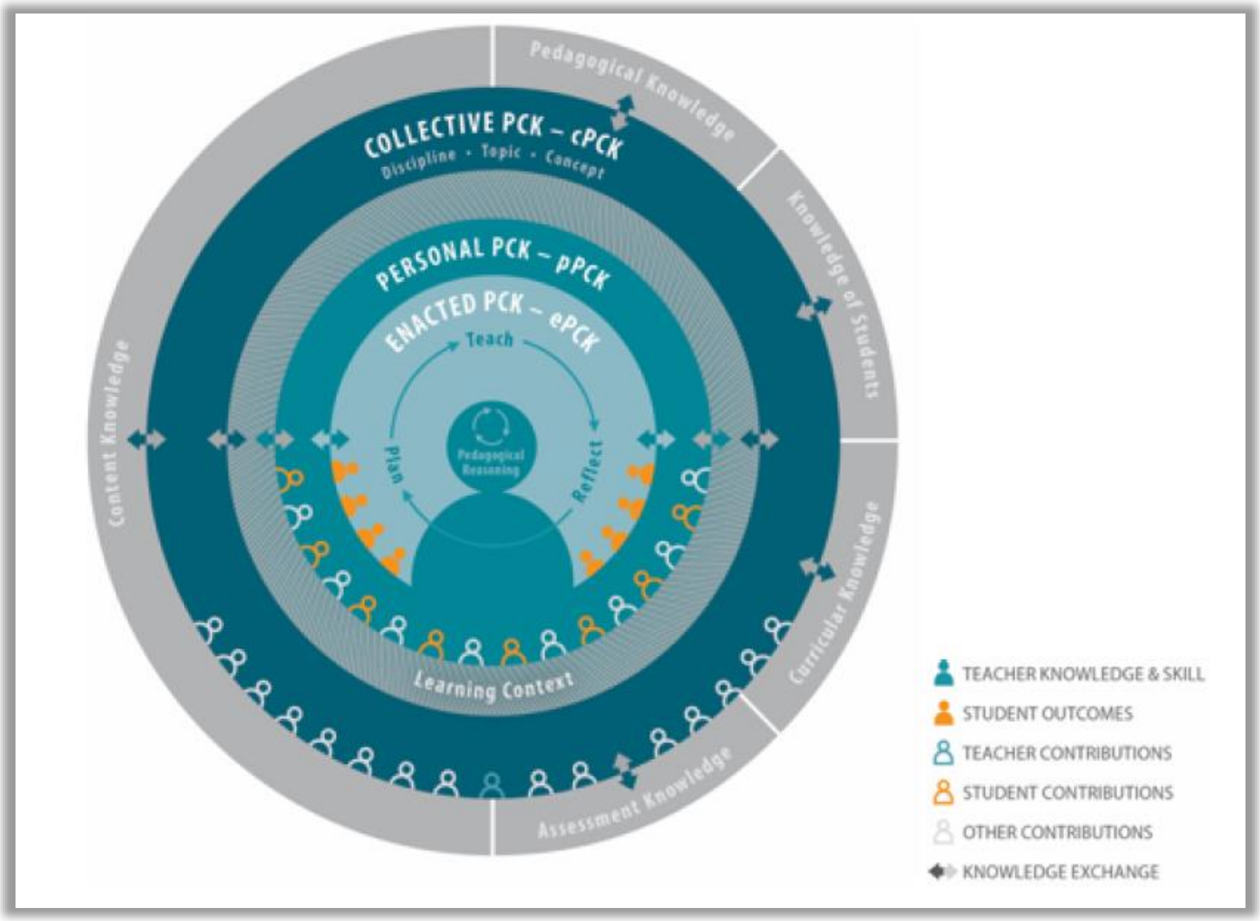


Figure 7-3: Representation of the 2017 Refined Consensus Model of PCK (Carlson & Daehler, in press)

Contributions related to methodology and data analysis

This study contributed an expert CoRe (Appendix H) about electromagnetism to the science teaching profession. The expert CoRe was constructed for Gr 11 electromagnetism in the South African school curriculum and is as such, an extensive, though not exhaustive, portrayal of knowledge about teaching this topic. It can be considered canonical PCK about electromagnetism and could be used by science teacher educators and novice teachers as a guideline for training and teaching and as a yardstick to assess TSPCK.

The validated rubric for scoring the CoRes about electromagnetism is another valuable contribution of this study. A CoRe rubric (Appendix G) was designed to score the responses of the participants on a four-level scale. The responses of the students were co-scored by three coders, which led to repetitive revision of the level descriptors in the rubric to align them with the levels of knowledge displayed by the students. Finally, the scoring was subjected to a Rasch analysis that flagged prompts for which the level descriptors did not adequately distinguish between neighbouring levels. Thus, the final CoRe rubric is a scoring instrument that went through rigorous validation and can be used by other researchers in the field.

Rasch analysis of the data in this study provided informative results. Using racked data, that means placing the items of the pre- and post-tests on the same ruler, enabled me to compare the item difficulties of the tests as experienced by the participants. I could establish in which items the students improved and which items were least affected by the intervention. Stacking pre-and post-test data required the two tests to be the same. The participants were regarded as "two sets of samples" who wrote the test at different times. By using person factors of *pre-* and *post-* the change in performance could be tracked. It was possible to obtain comparison graphs such as Figure 5-20 (p.98) and to determine which participants improved most. The technique of racking and stacking pre- and post- intervention data used in this study, provides a novel way of analysing data in PCK development research.

7.7 Recommendations and suggestions

Arising from findings in this study, the following recommendations and suggestions related to science teaching, teacher education and further research in the field of development of PCK are made.

Science teaching: sequencing of concepts in the curriculum

The study showed that student teachers who attempted to teach Faraday's law without prior explanation of the idea of magnetic flux found that learners struggled to understand these concepts. Novice teachers do not have the experience to know that magnetic flux presents itself as a difficult concept and that learners would not easily understand what $\Delta\phi$ and $\frac{\Delta\phi}{\Delta t}$ means in Faraday's equation. They will therefore do what the novice teachers in this study did, and tackle Faraday's law as presented in the curriculum, without first making sure that learners have a proper understanding of magnetic flux. I suggest that science curriculum developers consider including magnetic flux explicitly as a separate concept in the curriculum, before Faraday's law.

Science teacher education

The student teachers in this study benefitted from the inclusion of the components of TSPCK at the hand of a topic that is notoriously difficult. Not only did their PCK about the topic develop; their CK also improved significantly. Even though not all the components of TSPCK were developed to the same extent during the intervention, the students became aware of the knowledge needed to teach content effectively and were able to enhance their development while reflecting about their teaching. It is acknowledged that teaching encompasses more than enactment of the five components of TSPCK, but many of the other aspects of teacher knowledge are addressed in other courses of the student teacher's undergraduate career. Science teacher educators normally do not have the time at their disposal to teach all the pedagogical aspects about all the topics in science to their students. A study by Mavhunga et al. (2016) nevertheless suggests that teachers are able to transfer their competence of teaching one topic, attained during an intervention, to other topics. In accordance with Mavhunga et al., the current study suggests that the components of TSPCK at the hand of core topics is included in the training of pre-service teachers to assist them to reason about teaching and develop the skill to enact the knowledge in the classroom.

At the institution where this study took place, science education students study most of the Physics topics related to the school curriculum during their first year, whereas the methodology to teach these topics is taught in the third and fourth year. The findings of this study accentuate the divide between content courses and methodology, which may have a negative impact on the TSPCK development of pre-service science teachers. As such, the study supports a suggestion for the synchronisation of the methodology and content courses in terms of content and the time presented.

Research in development of PCK

Referring to the model of teacher professional knowledge and skill, including PCK (Gess-Newsome, 2015, p. 31), discussed in section 2.2.1, this study addressed, in the context of the pre-service teacher, the relationship between Topic Specific Professional Knowledge (in this study represented by TSPCK) and the personal PCK of the teacher as revealed in classroom practice. The scope for further research lies in establishing the link between the personal PCK of the teacher and learner outcomes in terms of sound conceptual understanding and performance. This link lies not only in the obvious assumption that better PCK will result in better performance but equally important, in the way in which teachers use learner outcomes to inform their classroom practice and to shape their PCK.

7.8 Concluding remarks and reflection

As a science teacher educator it is important for me to know that what I teach my students contributes significantly to their development as teachers. Merely assuming that what I do in class is to my students' benefit is not enough. This study showed that training had a significant positive influence on the teacher knowledge of my students. However, evidence emerged that my students' knowledge about learner thinking did not develop to the same extent as the other components and that this had a negative impact on their enacted teaching strategies. Thus, I plan to dedicate more time during training to the discussion of learners' thinking about science concepts and expose my students to literature about misconceptions in various topics. I am also considering giving them multiple opportunities to make their PCK explicit by constructing CoRes on various topics and to practise these in mock lessons.

While doing this study I realised, reading the students' responses to CoRe prompts, that they did not always interpret the prompt as intended (see § 5.3.4). This misinterpretation often arose because of the lack of experience. I consider revising the CoRe prompts to encourage the students to reveal their pedagogical reasoning about the components of TSPCK. Table 7-1 below lists the prompts I intend to change, the reason for changing it and the prompt I consider using in future.

Table 7-1: Revision of CoRe prompts

Prompt in the CoRe used in this study	***Reason for revising the prompt***	***Revised prompt***
A4: What else do you know about this idea (that you do not intend learners to know yet)?	Pre-service teachers included knowledge not relevant at school level, referring to content they were exposed to in undergraduate courses.	*A4: What else do you know about this idea that learners may learn later?*

Prompt in the CoRe used in this study	***Reason for revising the prompt***	***Revised prompt***
B1: What do you consider difficult about teaching this idea?	Pre-service teachers included responses such as: "equipment not available", or "nothing is difficult to teach", but it became evident in the classroom that learners found the concept difficult to understand.	*B1: What do learners find difficult to understand and why*?
C1: What are typical learners' misconceptions when teaching this idea?	Pre-service teachers tend to refer to concepts learners find difficult to understand when teaching the new content as for B1.	*C1: What are typical learners' misconceptions about pre-concepts that affect the teaching of this key idea?*
D1: What teaching strategies would you use to teach this key idea?	Participants in this study mentioned strategies such as *group work* or *inquiry-based* without further explanation. Since the answer to this prompt encompasses knowledge revealed in all the other prompts, this prompt will be placed last.	*E1: Describe the strategy you will use to establish conceptual development of the key idea.*

Using the CoRe tool together with the grand PCK rubric template (Chan et al., in press) at topic level, necessitates regrouping of the prompts in Figure 2-2 (p.20) to fit the components of the rubric. Table 7-2 shows how I consider regrouping the prompts and include the suggested changes of Table 7-1.

Table 7-2: Suggested use of CoRe prompts together with the grand rubric at topic level.

PCK components	CoRe-Prompts
Knowledge and skills related to curricular saliency	• Selection of key ideas. • What do you intend the learners to know about this idea? • Why is it important for students to know this? • What concepts need to be taught before teaching this idea? • *What else do you know about this idea that learners may learn later*?
Knowledge and skills related to conceptual teaching strategies	• What representations would you use in your teaching strategy? • What questions would you consider important to ask in your teaching strategy? • *Describe the strategy you will use to establish conceptual development of the key idea.*
Knowledge and skills related to student understanding of science	• *What do learners find difficult to understand and why?* • *What are typical learners' misconceptions about pre-concepts that affect the teaching of this key-idea?* • What ways would you use to assess learners' understanding?
Integration between PCK components	There are no prompts in the CoRe tool that can be linked uniquely to this component. Assessment of this component needs careful consideration.

Above all, the study afforded me the opportunity to develop my own PCK about science teacher training in line with the framework of the study, which made it an enriching experience. I plan to do dedicated research to contribute to the training of excellent science teachers in this country.

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Appendices

Appendix A

Excerpt from the National Curriculum Statement (CAPS, 2011) pertaining to magnetism, electromagnetism and electrodynamics in the South African FET phase.

Overview of topics

Electricity & Magnetism	**Grade 10**	**Magnetism** (magnetic field of permanent magnets, poles of permanent magnets, attraction and repulsion, magnetic field lines, earth's magnetic field, compass), **Electrostatics** (two kinds of charge, force exerted by charges on each other (descriptive), attraction between charged and uncharged objects (polarisation), charge conservation, charge quantization,**Electric circuits** (emf, potential difference (pd), current, measurement of voltage (pd) and current, resistance, resistors in parallel) **14 hours**
	Grade 11	**Electrostatics** (Coulomb's Law, Electric field), **Electromagnetism** (Magnetic field associated with current-carrying wires, Faraday's Law), **Electric circuits** (Energy, Power) **20 hours**
	Grade 12	**Electric circuits** (internal resistance and series-parallel networks), **Electrodynamics** (electrical machines (generators, motors), alternating current) **12 hours**

GRADE 10 PHYSICS *(ELECTRICITY & MAGNETISM)* TERM 2

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
2 HOURS	**Magnetism**				
0.5 hour	Magnetic field of permanent magnets	• Explain that a magnetic field is a region in space where another magnet or ferromagnetic material will experience a force (non-contact) • Know that an electric field is a region in space where an electric charge will experience an electric force. Know that the gravitational field is a region in space where a mass will experience a gravitational force. Compare the magnetic field with the electric and gravitaional fields			Electrons moving inside any object have magnetic fields associated with them. In most materials these fields point in all directions, so the net field is zero. In some materials (ferromagnetic) there are domains, which are regions where these magnetic fields line up. In permanent magnets, many domains are lined up, so there is a net magnetic field.
1 hour	Poles of permanent magnets, attraction and repulsion, magnetic field lines.	• Describe a magnet as an object that has a pair of opposite poles, called north and south. Even if the object is cut into tiny pieces, each piece will still have both a N and a S pole • Apply the fact that like magnetic poles repel and opposite poles attract to predict the behaviour of magnets when they are brought close together	**Recommended practical activity for informal assessment:** Determine the pattern and direction of the magnetic field around a bar magnet	**Materials:** Sheet of A4 paper, a bar magnet, iron filings **Materials:** Sheet of A4 paper, a bar magnet, several small compasses	Magnetic fields are different from gravitational and electric fields because they are not associated with a single particle like a mass or a charge. It is never possible to find just a north pole or just a south pole in nature i.e. a magnetic monopole does not exist. At the microscopic level, magnetic fields are a product of the movement of charges.

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
		• Show the shape of the magnetic field around a bar magnet and a pair of bar magnets placed close together, e.g. using iron filings or compasses. Sketch magnetic field lines to show the shape, size and direction of the magnetic field of different arrangements of bar magnets			Field lines are a way of representing fields. The more closely spaced the field lines are at a point the greater the field at that point. Arrows drawn on the field lines indicate the direction of the field. A magnetic field points from the north to the south pole. Field lines never cross and can be drawn in all three dimensions. For simplicity, only two dimensions are usually shown in drawings
0.5 hour	Earth's magnetic field, compass	• Explain how a compass indicates the direction of a magnetic field • Compare the magnetic field of the Earth to the magnetic field of a bar magnet using words and diagrams • Explain the difference between the geographical North pole and the magnetic North pole of the Earth • Give examples of phenomena that are affected by Earth's magnetic field e.g. Aurora Borealis (Northern Lights), magnetic storms • Discuss qualitatively how the earth's magnetic field provides protection from solar winds			The geographic North and South Poles are the northernmost and southernmost points respectively of the Earth's axis of rotation.

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
6 HOURS	**Electromagnetism**				
3 hours	Magnetic field associated with current carrying wires	• Provide evidence for the existence of a magnetic field (B) near a current carrying wire • Use the Right Hand Rule to determine the magnetic field (B) associated with: (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Draw the magnetic field lines around (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Discuss qualitatively the environmental impact of overhead electrical cables	**Practical Demonstration:** Get learners to observe the magnetic field around a current carrying wire **Project:** Make an electromagnet	**Materials:** Power supply, wire, retort stand, cardboard, several compasses. Iron nail, thin insulated copper wire, two or more D-cell batteries, one pair of wire stripper, paper clips	A simple form of evidence for the existence of a magnetic field near a current carrying wire is that a compass needle placed near the wire will deflect.

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

Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
8 HOURS	**Electrodynamics**				
4 hours	Electrical machines (generators, motors)	• State that generators convert mechanical energy to electrical energy and motors convert electrical energy to mechanical energy • Use Faraday's Law to explain why a current is induced in a coil that is rotated in a magnetic field. • Use words and pictures to explain the basic principle of an AC generator (alternator) in which a coil is mechanically rotated in a magnetic field • Use words and pictures to explain how a DC generator works and how it differs from an AC generator • Explain why a current-carrying coil placed in a magnetic field (but not parallel to the field) will turn by referring to the force exerted on moving charges by a magnetic field and the torque on the coil • Use words and pictures to explain the basic principle of an electric motor	**Project:** Build a simple electric generator **Project:** Build a simple electric motor	**Materials:** Enamel coated copper wire, 4 large ceramic block magnets, cardboard (packaging), large nail, 1.5 V 25mA light bulb. **Materials:** 2 pieces of thin aluminium strips 3cmx6cm, 1.5 m of enamel coated copper wire, 2 lengths of copper wire, a ring magnet (from an old speaker) a 6cmx15cm block of wood, sandpaper and thumb tacks.	The basic principles of operation for a motor and a generator are the same, except that a motor converts electrical energy into mechanical energy and a generator converts mechanical energy into electrical energy. Both motors and generators can be explained in terms of a coil that rotates in a magnetic field. In a generator the coil is attached to an external circuit and mechanically turned, resulting in a changing flux that induces an emf. In an AC generator the two ends of the coil are attached to a slip ring that makes contact with brushes as it turns. The direction of the current changes with every half turn of the coil. A DC generator is constructed the same way as an AC generator except that the slip ring is split into two pieces, called a commutator, so the current in the external circuit does not change direction. In a motor, a current-carrying coil in a magnetic field experiences a force on both sides of the coil, creating a torque, which makes it turn.

Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
		• Give examples of the use of AC and DC generators • Give examples of the use of motors			**<u>A note on torque:</u>** Know that the moment of a force, or torque, is the product of the distance from the support (pivot point) and the component of the force perpendicular to the object.
4 hours	Alternating current	• Explain the advantages of alternating current • Write expressions for the current and voltage in an AC circuit • Define the rms (root mean square) values for current and voltage as $I_{rms} = \frac{I_{max}}{\sqrt{2}}$ and $V_{rms} = \frac{V_{max}}{\sqrt{2}}$ respectively, and explain why these values are useful. • Know that the average power is given by: $P_{av} = I_{rms}V_{rms} = \frac{1}{2}I_{max}V_{max}$ (for a purely resistive circuit) • Draw a graph of voltage vs time and current vs time for an AC circuit. • Solve problems using the concepts of I_{rms}, V_{rms}, P_{av}			The main advantage to AC is that the voltage can be changed using transformers (device used to increase or decrease the amplitude of an AC input). That means that the voltage can be stepped up at power stations to a very high voltage so that electrical energy can be transmitted along power lines at low current and therefore experience low energy loss due to heating. The voltage can then be stepped down for use in buildings, street lights, and so forth.

Appendix B

Study guide: Methodology of Physical Sciences (Physics section)

Study component ***Methodology of Physical Sciences - Physics section***

Purpose statement

This course is the methodology course for physics teaching. It is designed, together with the methodology of chemistry teaching, to prepare students for teaching Physical Sciences Grade 10 -12. The module contains sections in which the development of the following competencies will be addressed and supported:

- to interpret the core curriculum pertaining to the physics component of physical sciences,

- to plan and design lessons with insight and present it successfully

- to plan and administer assessment procedures

- to acquire teaching knowledge and skills

Learning Outcomes of JMN433

The student will be able to

(i) access, understand and use the information in the National Curriculum Statement (NCS) as included in the CAPS document

(ii) integrate skills and pedagogical content knowledge about the topics in the curriculum to design appropriate learning activities.

(iii) select and incorporate appropriate teaching strategies to transform content knowledge into understandable ideas for learners.

(iv) understand common barriers and misconceptions pertaining to specific contents and chose and design appropriate teaching strategies to address these.

(v) select and use appropriate resources in planning lessons and addressing misconceptions.

(vi) select and use appropriate demonstrations, experiments and examples to support conceptual teaching

(vii) design assessments for summative, formative and diagnostic purposes.

(viii) reflect on his/her own practice in order to improve his/her teacher knowledge and skills.

Theme 1: Teacher knowledge: PCK and TSPCK

Pre-contact:

Compulsory reading work (available on click-up):

Read the following articles and sections in book chapters and find the answers to the questions below. Don't be concerned if you do not understand every term or concept in the reading material; rather try to understand the essence of the articles and chapters.

1. Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational researcher*, 4-14.

   Focus on the following sections: The Missing paradigm (p. 7,8), A perspective on teacher knowledge (p. 9,10)

2. Shulman, L. S. (2015). Its genesis and exodus. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 3-13). New York: Routledge.

   Focus on the following sections: The birth of PCK, Connecting subject matter to pedagogy, Inferring the existence of PCK, Limitations of the original PCK formulation, PCK as a policy claim.

3. Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education, 17*(1-2), 113-125.

   Focus on p113 to p116

4. Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370-391.

   Focus on pp. 370-373, 376 – 378.

Find the answers to the following questions in the literature:

1. What do the acronyms PCK and TSPCK stand for?
2. Describe PCK in your own words
3. What is PCK according to Shulman?
4. Why do you think is PCK considered to be topic specific?
5. What is content knowledge and what does it mean to transform content knowledge?

6. How does knowledge of each of the TSPCK components transform content knowledge?

7. What does it mean to capture a teacher's PCK? How can a teacher's PCK about a certain topic be captured?

Contact session:

Class discussion on PCK , components of TSPCK and CoRes.

- Describe PCK in you own words.
- Why do you think is PCK said to be topic specific?
- The five components of TSPCK and its significance in transforming knowledge.
- How does a CoRe capture topic specific PCK?

Assessment:

Short test on reading material (30 min)

Theme 2: Curricular Saliency: Electromagnetism in the Gr 10-12 curriculum

Pre-Contact:

Consult the Gr10-12 Physical Sciences curriculum in the CAPS document and/or any school text book that are in line with CAPS. Study the content outlined in the document to prepare for a test on the following topics: Gr 10 Magnetism, Gr 11 Electromagnetism, Gr 12 Electrodynamics.

Assessment

Content knowledge test and individual CoRes on electromagnetism

Contact session:

Class discussion:

- What is the sequence in which topics related to electromagnetism are introduced in CAPS? Why?
- Can you identify possible gaps in the content in CAPS that can lead to lack of knowledge that need to be in place for certain topics? Which?
- Why is it important to understand the curricular saliency of topics?
- How can knowledge about the curricular saliency of topics help to transform the knowledge for teaching?

Theme 3: Conceptual Teaching strategies

Contact session

Discussion:

Think about a teaching strategy to teach: the magnetic field around a current carrying wire or loop, in the gr 11 electromagnetism curriculum.

- Discuss this teaching strategies in terms of:
    - important features of this strategy,
    - reasons for using this strategy,
    - employing a particular strategy for conceptual teaching.
- What other knowledge about the topic and about learners do you need to have when you plan your teaching strategy.

Theme 4: Learner prior knowledge and misconceptions: Magnetism Gr 10

Pre-contact:

Read Sağlam, M., & Millar, R. (2006). Upper high school students' understanding of electromagnetism. *International Journal of Science Education, 28*(5), 543-566. Focus on the introduction.

Think about:

- What is a misconception?
- What is the origin and nature of misconceptions in magnetism according to Sağlam & Millar?
- What other prior knowledge of learners should a teacher know about when preparing to teach magnetism and electromagnetism?

Contact session:

Class discussion

- Magnetism Gr 10 - Knowledge that should be in place before teaching electromagnetism Gr. 11

- Possible misconceptions and other shortcomings in the prior knowledge of learners in basic magnetism.
- Teaching strategies and approaches to address these misconceptions.
- Appropriate representations to support the teaching strategies.

Assessment:

Assignment: Answer the following questions

Question 1: Misconceptions

What according to literature is a misconception?
What kinds of errors or mistakes made by learners cannot be classified as misconceptions?

Question 2: Misconceptions in magnetism

What is the origin and nature of misconceptions in magnetism according to Sağlam & Millar (2006)

Question 3: Addressing misconceptions

Identify two misconceptions prevalent in learners of science regarding magnetism and discuss strategies you will employ to transform the correct knowledge and bring about conceptual change.

Theme 5: Representations: Teaching electromagnetism – Demonstrations

Contact session:

In the sections on Magnetism and Electromagnetism in Gr. 10-12, there are several concepts that would be better understood by learners if accompanied by a well presented demonstration or practical. Some of the apparatus that could be used in demonstrations in these sections are:

1. Bar magnet, compasses
2. Long straight conductor in frame with iron filings and small compasses
3. Solenoid, power source, connecting wires, small compasses
4. Cathode ray tube, high voltage source, connecting wires, bar magnets
5. Solenoid, galvanometer, connecting wires and bar magnets
6. A current carrying conductor in a magnetic field

Class discussion:

- How can each of the demonstrations be used to support the transformation of knowledge?
  Think about:
  - Aspects to focus on during the demonstration
  - Important questions to ask
  - Possible misconceptions that may arise
- Using PHet simulations to teach electromagnetism
- Using the right hand to represent the relationship between the directions of vector quantities in electromagnetism.
- Drawing magnetic fields - How to represent 3D magnetic fields on a 2D writing surface.

Theme 6: Identifying key ideas in electromagnetism (gr11)

Pre-contact:

- Compulsory reading:

Maloney, D. P., O'Kuma, T. L., Hieggelke, C. J., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. American Journal of Physics, 69(S1), S12-S23.

Design a mind map showing how the idea of magnetic flux links to other key and sub-ordinate ideas in electromagnetism and electrodynamics Gr 10-12

Contact session:

Class discussion:

- What are the key and sub-ordinate ideas when dealing with Electromagnetism in Gr11?
- What are misconceptions that learners may have when starting this topic and that may arise while teaching this topic? (Sağlam & Millar (2006) and Maloney et al.(2001))
- What topics or sub-topics are difficult to teach? Why?
- How do ideas in gr 10 and gr 12 link with the gr 11 topics? (PowerPoint presentation)
- Mind map

Assessment:

Do this assignment in pairs. Design a mind map with magnetic flux as a central idea. Clearly show how the other key and sub-ordinate ideas relevant to the Gr10-12 curriculum about magnetism link with magnetic flux.

Theme 7: Identifying key ideas in electrodynamics (gr12)

Teaching generators and motors Gr 12

Contact session:

Class discussion:

- What knowledge should be in place when teaching
  - Generators
  - Electric motors
- What is difficult to teach when dealing with generators and motors? Why?
- Using simulations available on the internet when teaching these concepts.

Theme 8: Putting your TSPCK into practice: Lesson design & presentation

Pre-contact:

Download the lesson planning form from click-up and study and acquaint yourself with the structure of the form.

Contact:

When a lesson is designed, four very important aspects (amongst others) need to be considered and planned. These aspects are outlined on the faculty lesson planning form for your teaching practice (PRO) module.

(i) The **outcomes (aims, objectives)** that the teacher wants to achieve.

The teacher consults the curriculum document and carefully decides which section of the work needs to be taught. The time allocation should also be taken into account. The teacher should then write down exactly what he/she wants the leaner to know, to understand, to be able to do at the end of the lesson. What the lesson outcomes are, determine the teaching strategy that would be used. (Killen, 2012)

(ii) The **introduction to the new topic**:

Here the teacher plans how to introduce the topic or topics. This can be a problem statement from the learners' real life environment; it can also be reference to topics already learned in previous weeks or years. The introduction must be related to the new content. Very often, a lesson is divided in several parts as the sub topics build on one another. Each of these parts can have its own introduction.

(iii) The **development** of the new content.

Very careful planning must go into this section of the lesson. Here the teacher plans the teaching strategies for the key ideas in the lesson. Different teaching strategies may be used in the course of the lesson. The teacher must consider and plan which practicals, demonstrations, video clips, etc. should be included to make the new content accessible to the learners – that is; to transform the content. Never may the school textbook be a teacher's only source of information for the planning of a lesson.

In this section, the teacher also considers possible questions he/she can ask to diagnose misconceptions or to establish the level of understanding and thinking of the learners. "Do you understand?" is not a good question to ask; because leaners usually respond by saying that they do understand. The teacher must think about questions that will encourage critical thinking, conceptual development and problem solving.

(iv) The **conclusion/ consolidation.**

In this part of the lesson, the teacher wants to establish whether the learner indeed reached the goals set for the lesson. Homework can be part of this section.

Assessment:

This assessment has four parts. The lecturer will assign a sup-topic from the curriculum to you. For this topic do the following:

1. Write an individual lesson CoRe with at least three key ideas.
2. Design a lesson for this topic. Use the faculty lesson planning form.
3. Present the development part of your lesson to your peers. (15 minutes)
4. Assess the lessons of at least three peers.

Theme 9: Assessment

Design a test that leaners will write at the end of the section on Electromagnetism grade 11. This test should consist of two sections: A. a diagnostic part where misconceptions and other alternative ideas will be revealed (at least 5 questions) B. a section (20 marks) with open ended questions to assess the understanding of the concepts.

Submit the test with a memorandum.

Appendix C

Structure of the intervention

		Activities	Assessments (Those marked with * will be part of the data for the project)	Link to research framework
Session 1 1 Feb 2016		• Introduction of research project • Consent forms • Announcement of the content knowledge test on magnetism, electromagnetism and electrodynamics (GR10-12 CAPS) (60 min) • Introductory discussion on of PCK, TSPCK and the components of TSPCK (introduce reading) (60 min) • Discussion of the CoRe template		
Session 2 4 Feb 2016	**Theme 1**	**Teacher knowledge: PCK and TSPCK (continue)** Reading : Shulman (1986), Shulman 2015, Mavhunga,& Rollnick (2013), Loughran et al. (2004) Discussion of CoRe Discussion questions: • Describe PCK in your own words • What is PCK according to Shulman? • Why do you think is PCK said to be topic-specific? • What is content knowledge and what does it mean to transform content knowledge? • How does knowledge of each of the TSPCK components transform content knowledge? • What does it mean to capture a teacher's PCK? How can a teacher's PCK about a certain topic be captured?	Test on articles (30 min)	TSPCK CoRes and TSPCK components
Session 3 8 Feb 2016		CK Test (60 min) Complete first personal CoRe on Gr 11 electromagnetism – three big ideas Gr 11 (60 min) Students had access to the CAPS document while writing the CoRes	* CK Test and Initial personal CoRe on electromagnetism (Pre-CoRe)	

		Activities	Assessments (Those marked with * will be part of the data for the project)	Link to research framework
Session 4	**Theme 2**	**Curricular saliency** Unpack magnetism and electromagnetism from CAPS • What is the sequence in which topics are introduced? Why? • Can you identify possible gaps in the content in CAPS - knowledge that need to be in place for certain topics? • Why is it important to understand the curricular saliency of topics? • How can knowledge about the curricular saliency of topics help to transform the knowledge for teaching?		**Curricular saliency**
Session 5	**Theme 3**	**Conceptual teaching strategies** Discussion topics: • Employing a particular strategy for conceptual teaching, • Thinking about key ideas and sub-ordinate ideas where each particular strategy can be used and how it can be used. • Considering other knowledge required of the topic and about learners when planning a strategy. • Discussion of possible teaching strategies		**Conceptual Teaching Strategies**
Session 6	**Theme 4**	**Learner prior knowledge and misconceptions** Reading: Saglam & Millar (2006) Discussion • Magnetism Gr 10 - Knowledge that should be in place before teaching electromagnetism Gr. 11 • Possible misconceptions and other shortcomings in the prior knowledge of learners about basic magnetism ideas • Suggest teaching strategies, approaches and representations to address these misconceptions. Assignment: 1. What is a misconception? 2. What are the origin and nature of misconceptions in magnetism according to Sağlam and Millar (2006)?	Assignment: Magnetism Gr 10 - misconceptions	**Curricular saliency** **Prior knowledge** **Teaching strategies** **Representations**

		Activities	Assessments (Those marked with * will be part of the data for the project)	Link to research framework
		3. Identify two misconceptions prevalent in leaners of science regarding magnetism and discuss strategies you will employ to transform the correct knowledge and bring about conceptual change.		
Session 7	**Theme 5**	**Representations:** Focus on specific apparatus, practical demonstrations and simulations that can be used when teaching electromagnetism Class discussion: • How can each of the demonstrations be used to support the transformation of content knowledge? Think about: • Aspects to focus on during the demonstration • Important questions to ask and the sequencing of questions • Possible learner difficulties that can be addressed • Possible misconceptions that may arise • Using PHet simulations to teach electromagnetism • Using the right hand to represent the relationship between the directions of vector quantities in electromagnetism • Drawing magnetic fields - How to represent 3D magnetic fields on a 2D writing surface.		**Teaching strategies** **Representations**
Session 8	**Theme 6**	**Identifying key ideas in electromagnetism (gr11)** Class discussion: • What are the key and subordinate ideas when dealing with electromagnetism in Gr11? • What are misconceptions that learners may have when starting this topic and that may arise while teaching this topic? (Sağlam & Millar, 2006; Maloney et al., 2001) • What topics or sub-topics are difficult to teach? Why? • How do topics in Gr 10 and Gr 12 link with the Gr 11 topics? • Mind map		**Curricular Saliency** **Prior knowledge** **What is difficult to teach?**

		Activities	Assessments (Those marked with * will be part of the data for the project)	Link to research framework
Session 9	**Theme 7**	**Identifying key ideas in electrodynamics (gr12)** Teaching generators and motors. Class discussion: • What knowledge should be in place when teaching • Generators • Electric motors • What is difficult to teach when dealing with generators and motors? Why? • Using simulations available on the internet when teaching these concepts.		**Curricular saliency** **Representations** **What is difficult to teach?**
Session 10	**Theme 8**	**Putting your TSPCK into practice** **Drawing the five components of TSPCK together** Discuss lesson design and presentations. Finalise mid-intervention CoRe for lesson	Assignment: (i) mid-intervention CoRe (ii) Design lesson Lesson presentation	**Transferring TSPCK to practice**
Session 11		Lesson presentation and peer assessment.		
Session 12	End of interven-tion	Lesson presentation and peer assessment.		
Session 13	**Theme 9**	Assessment Designing a test	Assignment: Design diagnostic test	**What is difficult to teach** **Prior knowledge, misconceptions**
Session 14		CK test Complete a second personal CoRe on Gr 11 electromagnetism	* Second CK test * Second CoRe (Post-CoRe)	

Appendix D

Reflective journal

Theme 1: PCK and TSPCK

Before the session the students were instructed to read four articles about PCK and topic specific PCK. During the class discussion, it became evident that the students put in an effort to read the articles because they could answer questions such as: What was Shulmans idea about PCK? What are the knowledge bases that the teacher functions from?

The students were asked whether they could, from their experience, understand that PCK is considered to be topic specific. They responded that they could indeed understand the notion that PCK is topic specific, because many of them had experience teaching extra classes to gr 10- 12 learners and they realized that they were more confident in teaching certain topics than others. Some of them mentioned electric circuits, newton's laws and chemical reactions as topic they were confident in, because they knew the content better. There were three students who mentioned electromagnetism as a topic they were definitely not confident in.

From the reading the students had to do and from the class discussion the students started to formed an idea of the meaning of each of the components of topic specific PCK. In general, the students did not have a clear idea of the relevance or significance of knowledge about the curriculum, that is, the curricular saliency of topic. They also did not realize how the other components would contribute to their ability to transform content into ideas that is understandable to learners. At the end of the discussion however, they agreed that if they had the knowledge of those five components about any given topic they would have confidence to teach it.

Yet, when they were prompted about their perceptions about their own teaching, it was clear that what they read and discussed about PCK was not yet internalized and not considered an idea in terms of which they could think about themselves and their own teaching.

The discussion was consolidated by the following question: Suppose you were a senior teacher and the principal asked you to assess the level of the PCK of a novice teacher on a certain topic, what would you be looking for?

I expected that the students would refer to the five components of topic specific PCK. It was surprising that students focussed primarily on the other knowledge bases of teachers and in a sense ignored topic specific PCK. Their answers included:

The teacher should be able to maintain discipline.

The teacher should not make mistakes on the board.

The teacher should be able to use an overhead projector or data projector if available.

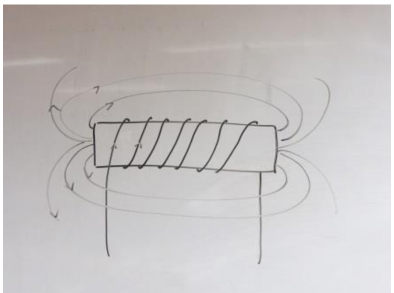
The teacher should speak clearly and talk to all the learners in the class.

The teacher must be well prepared

I again reiterated the importance of knowledge of the five components.

Theme 2: Curricular Saliency

The rationale behind doing this in the second theme was for students to have a sound idea of the content of magnetism and electromagnetism in the school curriculum when dealing with the upcoming themes. This was indeed necessary because the CK test showed that their content knowledge about the topic was inadequate. Although all the students had at least a first year of undergraduate physics, some of them cannot even remember that they studied the topic. Some of them did not remember that the topic was taught during their years at school. When I drew a particular diagram in an attempt to remind them of the work done, they recognised it, but some only vaguely.



The discussions did not proceed in the way I anticipated. I hoped that after studying for the CK test, they will at least have an idea of the schoolwork, but that was not the case. The idea was to remind them of the topics in this theme while briefly unpacking the curriculum, but because of their obvious lack of content knowledge, I was compelled to discuss and explain content in this session. I decided to use the PowerPoint presentation intended for theme 5, to briefly remind the students of the some of the important concepts.

I also wanted them to realize that the Lorentz force is not explicitly referred to in the curriculum, but only mentioned in the teachers' guidelines. The students were at this stage not able to identify the obvious gap in the curriculum concerning the Lorentz force required to understand the electric motor.

Theme 3: Conceptual teaching strategies

In this theme, teaching strategies were discussed. Learning about teaching strategies is an outcome of the methodology module so that students are able to complete section 5.3 in their lesson planning form.

For this reason, the following teaching strategies were discussed: discussion (question and answer), inquiry-based learning, small group work, problem solving and direct instruction. During this session, I wanted to link the mentioned strategies for teaching to conceptual strategies focusing on teaching magnetism and electromagnetism. During the discussion, students identified the following components of a successful teaching strategy:

- Proper planning including:
    - demonstrations and experiments that would support conceptual understanding.
    - How to explain concepts that learners usually struggle to understand (many students did not have an innate understanding that this is important to keep in mind when planning a lesson)

- Involve learners
- Speak clearly and making eye contact

My perceptions:

- Students tend to focus on aspects of general pedagogy like making eye contact, speaking clearly, involving all learners etc.
- Students are more comfortable with direct instruction as a teaching method than any of the other methods.
- Students have not developed the skill of asking questions that require higher order thinking skills.
- When prompted and guided, students recognize aspects of teacher knowledge related to TSPCK.

Theme 4: Learner prior knowledge and misconceptions

I started the session by handing each student two tiny compasses and a magnet. They had to verify which end of the magnets point towards the north pole of the magnet. Then putting the magnets away, they had to predict which end of the magnet would point towards North in the earth's magnetic field. None of the students was able to predict this correctly (even though the earth's magnetic field appears as a topic in the gr 10 curriculum)

Students often do not distinguish between north and south poles and negative and positive charges and will easily talk about the negative pole of a magnet. This is a typical misconception found amongst learners. I came across this

When asked about typical misconception about magnets that they know about, the students mentioned and discussed the following:

- One student mentioned that learners think that magnets attract all metals. This led to a discussion among the student's because some of them had the same idea. When asked which metals are attracted by magnets many named copper and aluminium as two of the metals.
- Learners think that if you cut a magnet in half, you will separate the north and south poles. This is a well-known idea learners have and is addressed in the curriculum.
- They suggest that learners think that nothing will happen to a magnet if you let it fall. When prompted about why one should not let a magnet fall, the students were not able to give a reason.
- They realized that learners probably don't know that a compass needle is a magnet itself (While they themselves had the same difficulty)

Theme 5: Representations

The session was mainly devoted to demonstrations related to teaching electromagnetism and diagrams that could be used. The following demonstrations were shown:

5.1 The existence of a magnetic field around a long straight current carrying conductor.

Apparatus: long straight conductor on a wooden frame connected to a source with iron filing and tiny compasses

Questions: What can I conclude in general when iron filings move around or compass needles redirect in a certain space? Why do the iron filings (or the compasses) behave the way they do when the current is switched on?

Teaching guidelines: I alluded students to the fact that this is a good place to introduce the right hand rule. Also show right hand rule during demonstration. Show how diagrams are drawn to represent the wire and magnetic field.

5.2 The magnetic field around a current carrying coil.

Apparatus: A copper coil on a wooden structure connected to a source and tiny compasses.

The drawing a coil on the board was discussed and practised.

5.3 A moving charge experiences a force in a magnetic field.

Apparatus: A cathode ray tube connected to a high voltage source and magnets.

The right hand rule for determining the direction of the force was discussed.

5.4 A current carrying coil in a magnetic field experiences a force.

Apparatus: strip of aluminium foil suspended between two crocodile clips connected to power source (with rheostat) and magnets.

The key idea (force on a moving charges or a current carrying conductor in a magnetic field) addressed in 5.3 and 5.4 does not appear in the curriculum, but is required as existing knowledge in electrodynamics gr 12. Students were again alerted to this possible gap in the knowledge of learners.

5.5 Inducing a current in a coil when magnets move in and out of the coil.

Apparatus: copper coil on wooden structure connect to galvanometer and bar magnets.

Students responded very positively to all the demonstrations. Many of them commented that this was the first time that they could remember seeing demonstrations like these. I emphasized the fact that the way these demonstrations are presented contribute to the effectiveness of transforming the content for conceptual understanding. I also demonstrated to them how the questions the teacher ask (the type and the timing) will support learners to use their prior knowledge to construct new knowledge. We again discussed diagrams that can be used when explaining concepts by referring to the PowerPoint presentation.

During this session, we also discussed the effectiveness of computer simulations showing the same concepts the demonstrations show. We used PhEt simulations on electromagnetism. The students agreed that simulations are indeed a good support for teaching these concepts, especially in classrooms where the apparatus are not available. They were in accord that if possible one should try to show the actual demonstration first and then for clarity show the simulations; since learners know that computer simulations can be "cheated".

Theme 6: Identifying key ideas in electromagnetism (gr11)

Once again, this session did not proceed in the way I initially anticipated; the main reason being the persistent lack of content knowledge of the students (although it was steadily improving). During the previous sessions, I became aware that the lack of content knowledge still hindered students' appreciation of the importance of the components of TSPCK, because they are focussed on organizing their own prior knowledge about electromagnetism and filling the gaps, rather than thinking how to teach the topic.

When prompted, the students selected the two headings in the CAPS document as key ideas and added the right hand rule as a third key idea, as they did in their initial CoRe. Even after the students were exposed to the content in previous sessions, they still did not have a clear idea of how they would sequence the topics and what they would select as key ideas.

We had a discussion on what should be taught before the equation stating Faradays' law should be presented. I felt that students started to realize that a discussion of magnetic induction as a physical phenomenon and magnetic flux as a concept to explain induction can be explained before they talk about Faraday's law and use it in solving problems.

Theme 7: Identifying key ideas in electromagnetism (gr12)

During this session I briefly introduced the content of electrodynamics as required in the Gr 12 curriculum. Simulations were discussed. Students again struggled to predict the direction of rotation of a current carrying coil in a magnetic field and we went through the application of the right hand rule for this situation again. It seemed as if the students grasped for the first time the necessity of addressing the concept of forces acting on a current carrying conductor in a magnetic field explicitly, rather than the cursory way it is addressed in the curriculum.

Theme 8: Putting TSPCK into practice

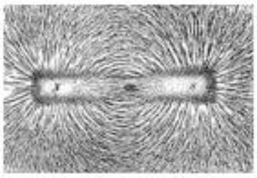
Although students claim that they will not be using direct teaching as a teaching strategy during their lessons, they all fall back on this method of teaching; probably because that is the example they had for twelve years while being learners themselves. They say that they feel in control when they are teaching in this way and that they know they have covered all the content when they rote teach. The questions they ask do not require higher order thinking skills. I saw however that the students made attempts to really use useful representations in the lessons. I kept in mind that a micro lesson situation, which they do in front of peers, is superficial. The discussions and comments by peers after each lesson again focussed on aspects of general pedagogy such as body language, use of voice, eye contact and involving the "learners". At the end of the intervention, I felt that I needed much more time with the students and that they needed much more time for practicing and applying the new knowledge.

Appendix E

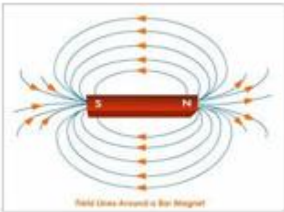
PowerPoint presentation for theme 5 of the intervention

Magnetic field

- Symbol: B, Unit: Tesla
- Magnetic field of a bar magnet:
  - Iron filings

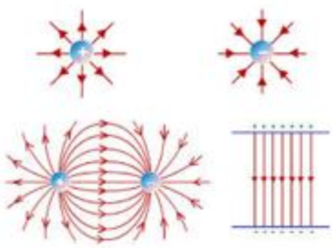


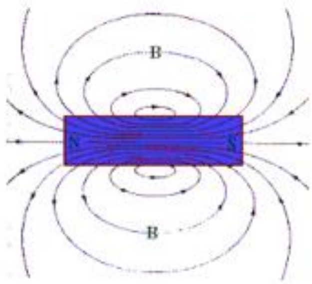
  - Field lines



  - Compasses

- Note:
  - The difference between an E-field and a B-field

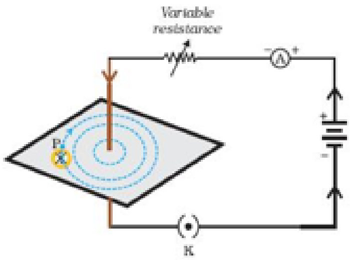




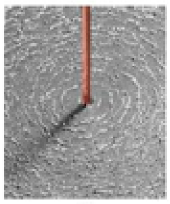
  - The field gets weaker with distance from the magnet

Where else do I find magnetic fields?

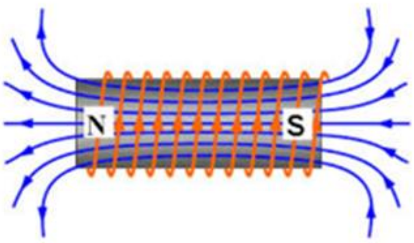
- Demonstration 1 (long straight current-carrying conductor)
  - Determine direction with right-hand rule

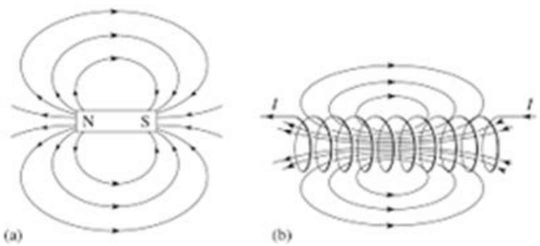


(a)


(b)

- Demonstration 2 (current-carrying coil)

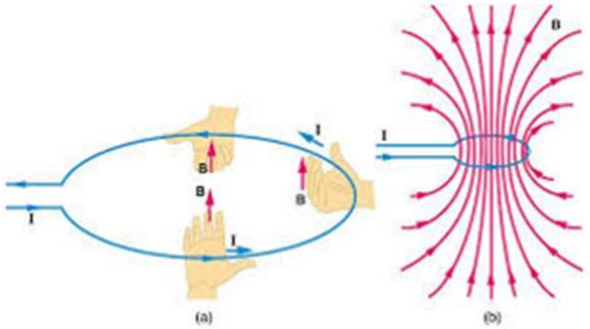


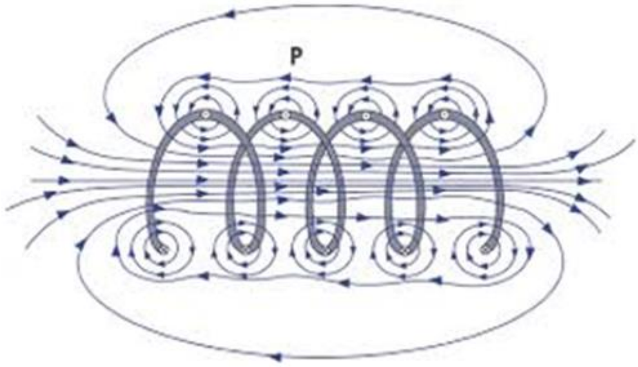


(a) (b)

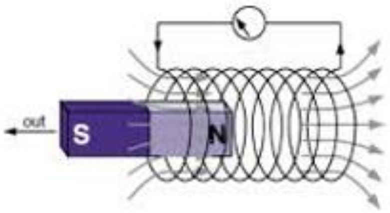
  - Why can an electromagnet be switched on and off?
  - There is only a magnetic field when there is a current.

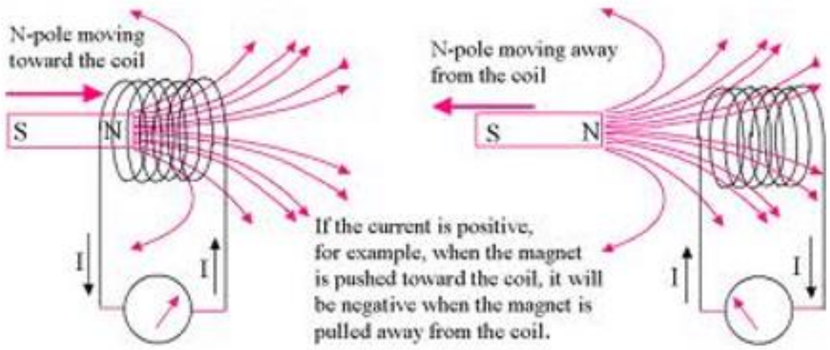
Magnetic field of a current-carrying coil.





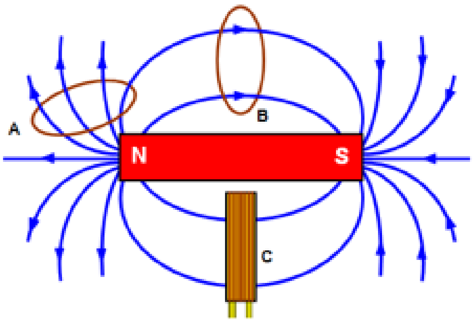
- Induced current: Demonstration: coil with magnet

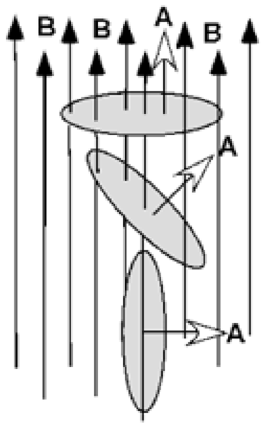




Magnetic flux

- Symbol: Φ Unit: Weber
  - Can be seen as the amount of magnetic field (the number of field lines) that passes **through** a loop.

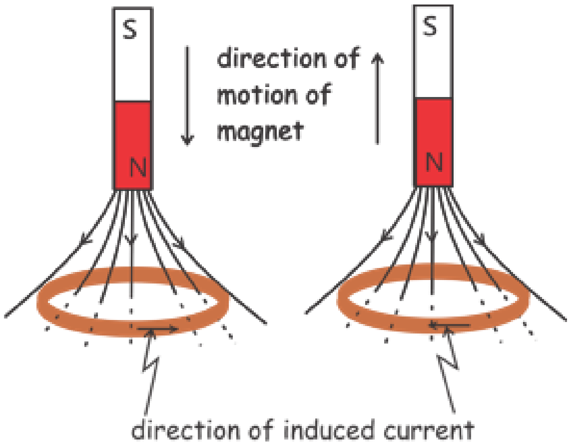




  - Def. $\Phi = BA\ cos\theta$

What will happen if I move a magnet in a coil?

- What is meant by: the magnetic flux through a coil changes?



  - The number of field lines that "cuts" through the loop changes

- How can I induce **more** current?

Show with actual apparatus and simulation

- – Increase the number of loops: Symbol N
- – Use a stronger magnet. (Why?) (more magnets)
- – Move the magnet faster (or move the coil faster)
  - That is: the "rate of change of flux" is bigger
  - Symbolic representation for "rate of change of flux"

$$\frac{\Delta\Phi}{\Delta t}$$

Faraday's law: $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$

What do you know about this topic that learners don't learn yet (in Gr11)?

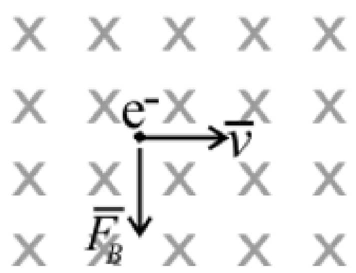
- A magnetic field is defined by the force a moving charge experiences in the magnetic field.

$$B = \frac{F_B}{qv}$$

$$\bar{F}_B = q\bar{v} \times \bar{B}$$

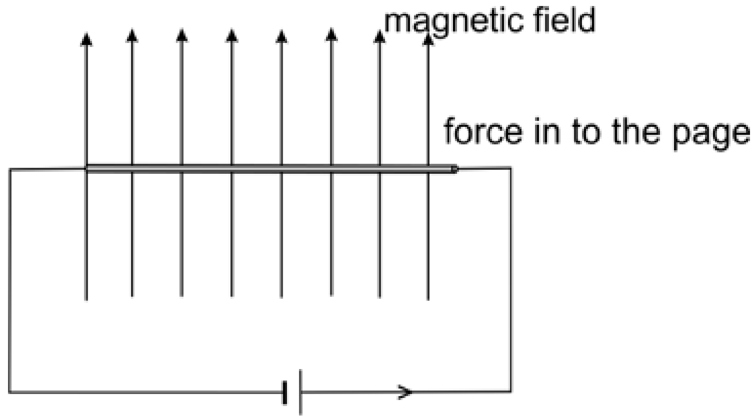
magnetic field into the page

Determine the direction of the force with the right-hand rule



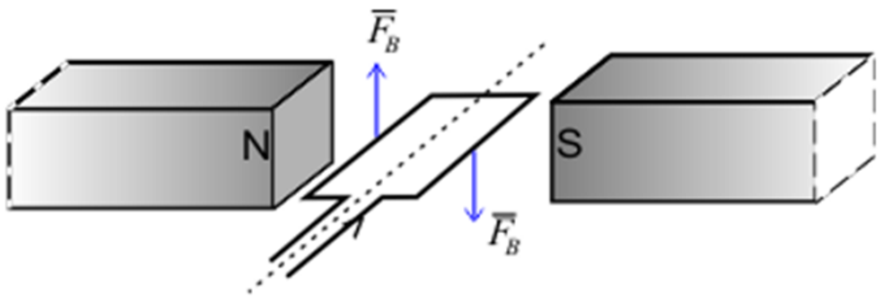
- Magnetic force on a current carrying wire

$$\bar{F}_B = I\bar{L} \times \bar{B}$$

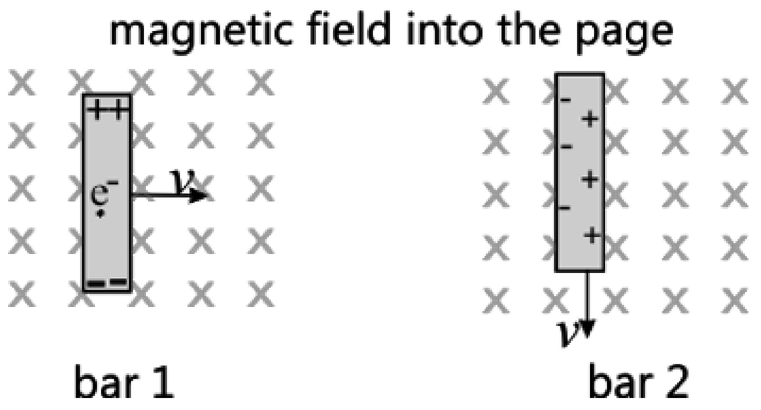


Apply right hand rule to determine direction: fingers in direction of current, then curl in direction of magnetic field, thumb points in direction of force.

- Torque on a current-loop



• Metal strip in a magnetic field → induced emf.



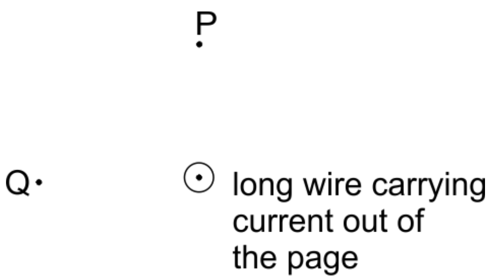
Appendix F

Content knowledge test

Please answer the questions on the answer sheet by writing the answer you consider as correct in the appropriate block. **Submit the question paper with your answer sheet.**

Question 1

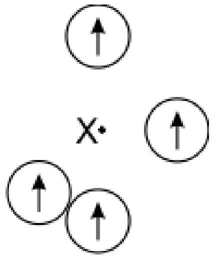
1.1 The diagram shows a long straight wire, perpendicular to the plane of the paper. The current in the wire is upwards out of the paper. The points P and Q are the same distance from the wire.



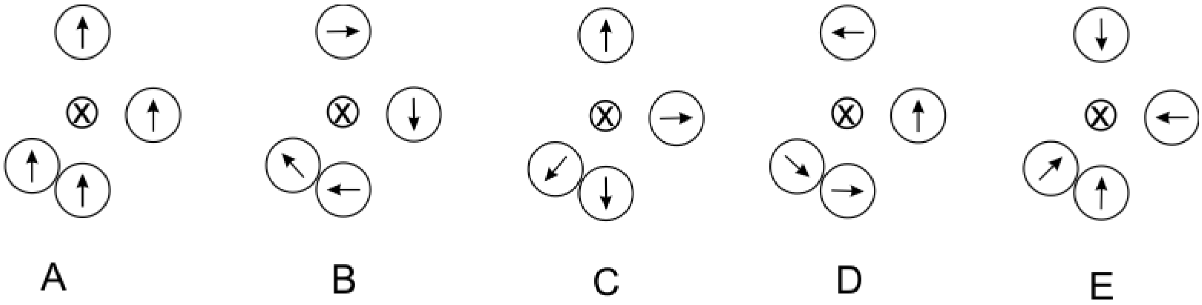
What is the direction of the magnetic field at points P and Q?

	Direction of the magnetic field at P	Direction of the magnetic field at Q
A	↓	→
B	←	↓
C	↑	←
D	→	↑
E	into the page	into the page
F	out of the page	out of the page

1.2 The diagram shows four compasses that are placed on a flat surface. They are orientated as shown because of the earth's magnetic field.

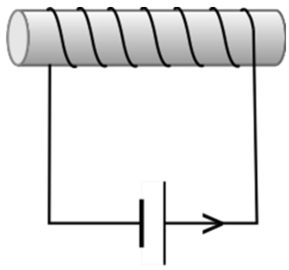


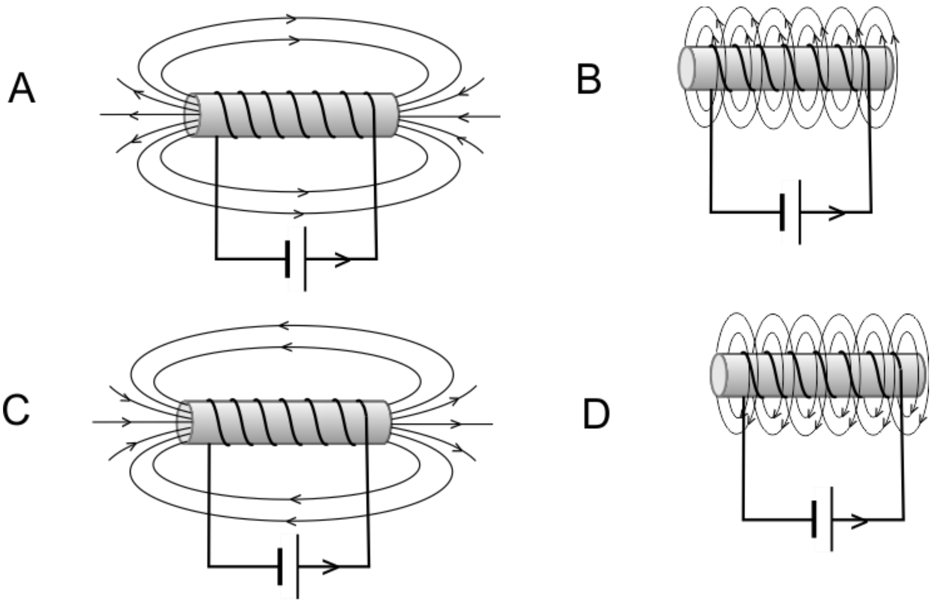
A wire carrying current into the surface, is placed through a hole in the surface at point X between the compasses so that the wire is perpendicular to the plane. Which diagram below shows best the orientations of the compasses with the current carrying wire at rest in position as shown?



Question 2

A wire coil is wound around a tube and is connected to a cell. It carries current as shown. Choose the diagram that best represents the magnetic field around the coil.

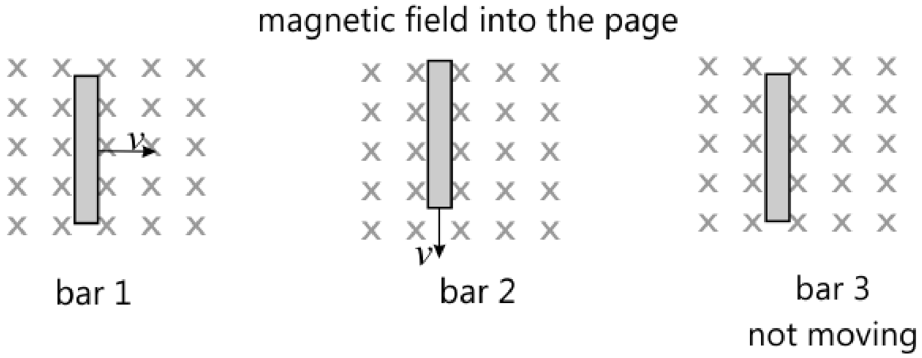




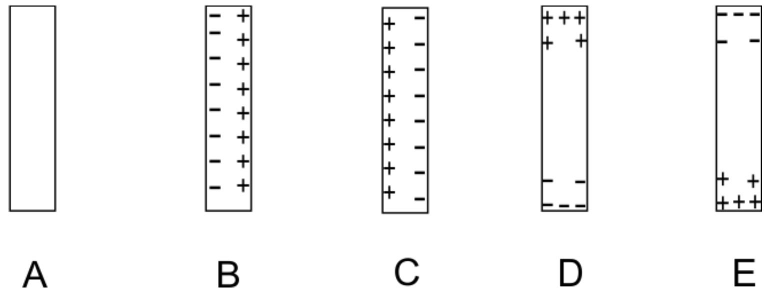
E There is no magnetic round the coil, only an electric field.

Question 3

Three identical metal bars are in magnetic fields with the same magnitude. The direction of the field is into the page. Bar 1 and bar 2 are moving with constant speed in the directions shown and bar 3 is at rest.



Use the following options to answer questions 3.1, 3.2 and 3.3.



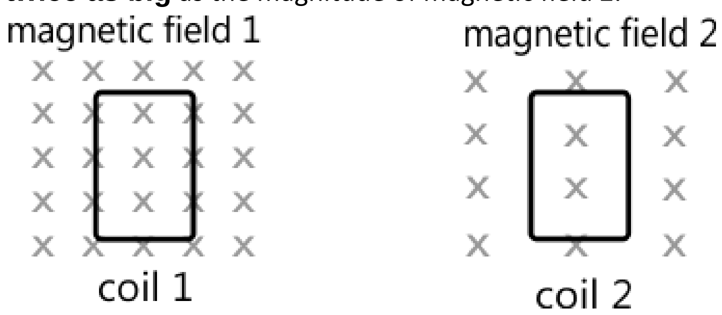
3.1 Which diagram shows the charge distribution in bar 1?

3.2 Which diagram shows the charge distribution in bar 2?

3.3 Which diagram shows the charge distribution in bar 3?

Question 4

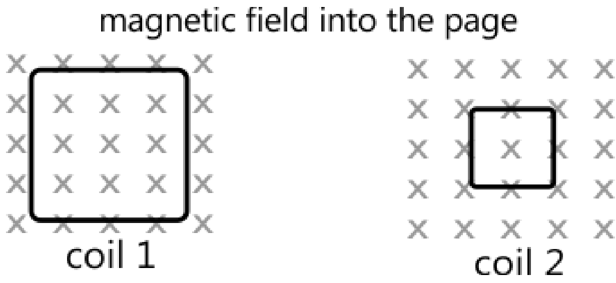
4.1 Two identical flat coils are placed in two different uniform magnetic fields. The **magnitude of magnetic field** 1 is **twice as big** as the magnitude of magnetic field 2.



How does the magnetic flux through coil 1 compare with that through coil 2?

A. it is four times as big as that of coil 2
B. it is twice as big as that of coil 2
C. it is the same magnitude
D. it is half as big as that of coil 2
E. it is one quarter as big as that of coil 2

4.2 Two flat square coils with the same number of turns are placed in the same uniform magnetic field. The **side lengths** of coil 1 are **twice as long** as that of coil 2.



How does the magnetic flux through coil 1 compare with that through coil 2?

A. it is four times as big as that of coil 2

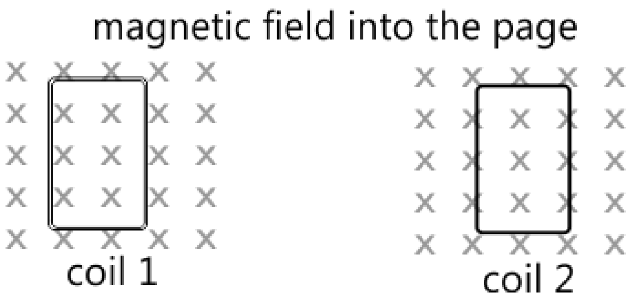
B. it is twice as big as that of coil 2

C. it is the same magnitude

D. it is half as big as that of coil 2

E. it is one quarter as big as that of coil 2

4.3 Two flat coils with the same area are placed in the same uniform magnetic field. The **number of turns** of coil 1 is **twice as many** as the number of turns of coil 2.



How does the magnetic flux through coil 1 compare with that through coil 2?

A. it is four times as big as that of coil 2

B. it is twice as big as that of coil 2

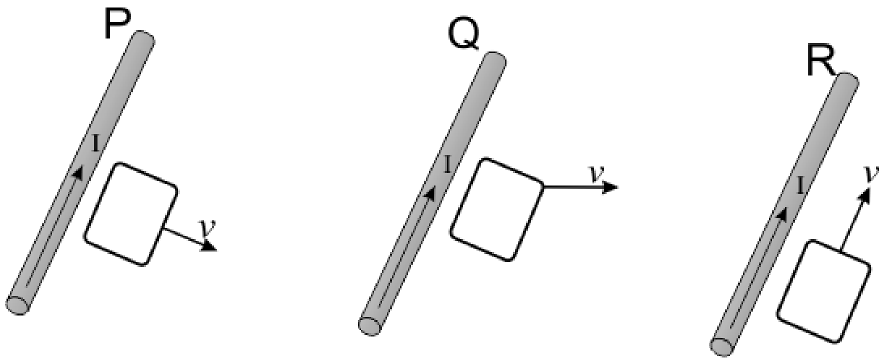
C. it is the same magnitude

D. it is half as big as that of coil 2

E. it is one quarter as big as that of coil 2

Question 5

A very long straight conductor carries a large steady current I. Rectangular metal wire loops, in the same plane as the conductor, move with a velocity v in the directions shown.



In which loop(s) will a current be induced?

A. only P and Q

B. only R and Q

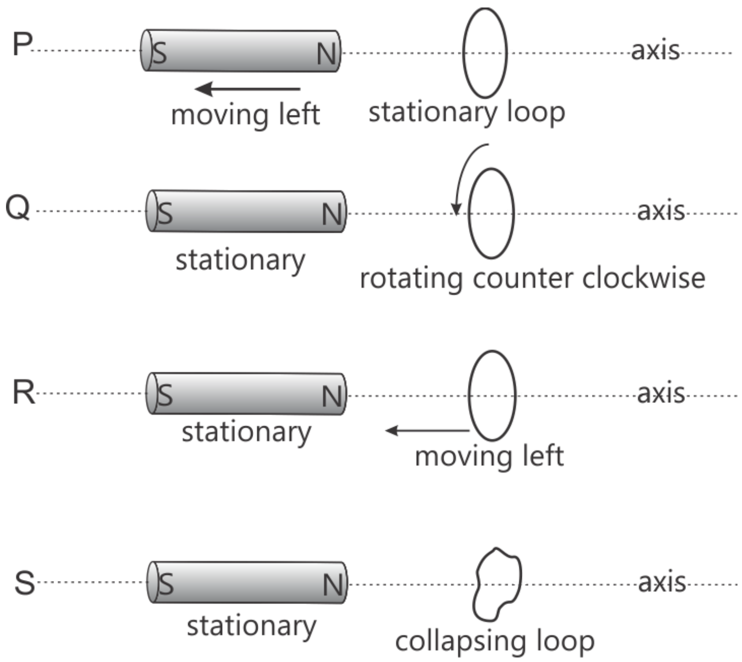
C. only P and R

D. P, Q and R

E. None

Question 6

The four separate figures below involve a separate magnet and a loop made of copper wire. The plane of the wire loop is perpendicular to the reference axis. In each case the states of motion of the magnet and wire loop are indicated in the diagram.



In which of the above situations will current be induced in the loop.

A. Only in P

B. Only in P and R

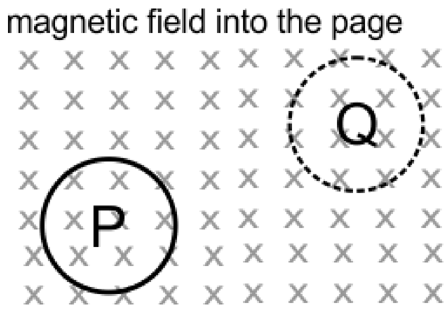
C. In P, Q and R, but not S

D. In P, R and S, but not Q

E. In all of them.

Question 7

A wire loop in the shape of a circle is placed in a uniform magnetic field. The circle is moved from position P in the field to position Q.



Which statement about an induced current in the loop is true?

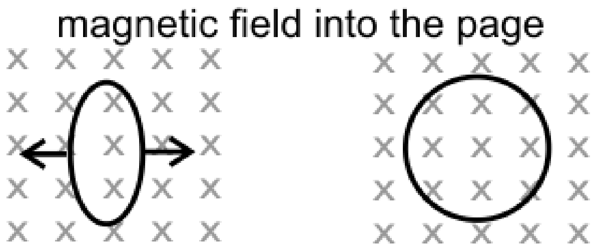
A. No current is induced in the loop

B. The induced current in the loop is clock wise

C. The induced current in the loop is counter clockwise.

Question 8

A wire loop in the shape of a flat ellipse is placed inside a magnetic field directed into the page. The ellipse is then pulled to the sides to form a circle, as shown in the diagram.



Which statement about an induced current in the loop is true?

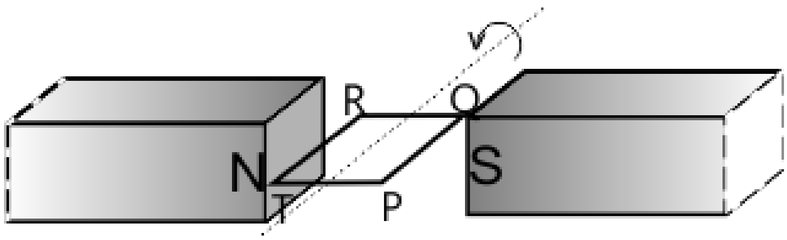
A. No current is induced in the loop

B. The induced current in the loop is clock wise

C. The induced current in the loop is counter clockwise.

Question 9

A wire loop (PQRT) is placed between two magnets as shown in the diagram. An external agent rotates the loop counter clockwise around an axis parallel to the long sides of the loop (PQ moves up and TR moves down).



Which statement about an induced current in the loop is true?

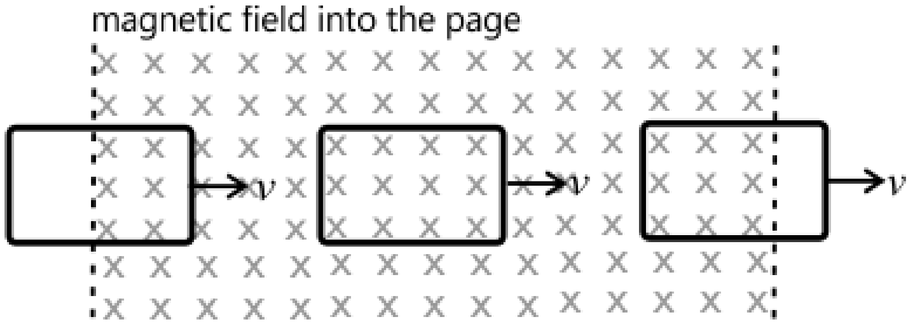
A. No current is induced in the loop when the loop is orientated and rotated as shown

B. The induced current in the loop is counter clock wise (form P to Q when the loop is orientated as shown)

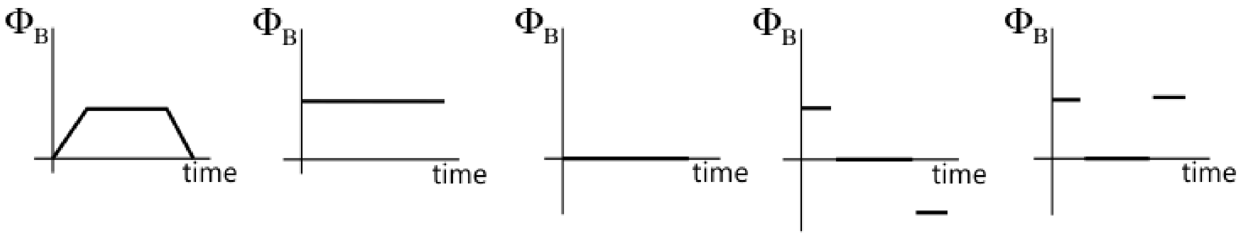
C. The induced current in the loop is clockwise (from Q to P when the loop is orientated as shown)

Question 10

The diagram shows a flat rectangular coil moving at constant speed in a uniform magnetic field. The magnetic field is confined to the region indicated by the dashed lines.

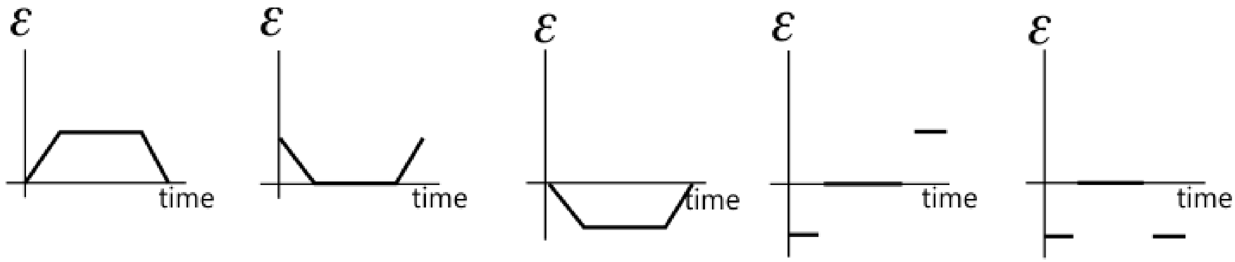


10.1 Which one of the graphs below shows how the magnetic flux Φ_B through the coil changes from the moment it enters the field until the moment it leaves the field?



A B C D E

10.2 Which one of the graphs below shows how the induced emf ε in the coil changes from the moment it enters the field until the moment it leaves the field?



A B C D E

Question 11

The diagrams show long straight wires current carrying wires in magnetic fields with directions of the current and the magnetic fields as shown. The questions are about the forces the wires experience. Choose for each of the diagrams an answer from the list of options.

In which direction will the wire experience a force?

A. The wire will not experience a force

B. to the left

C. to the right

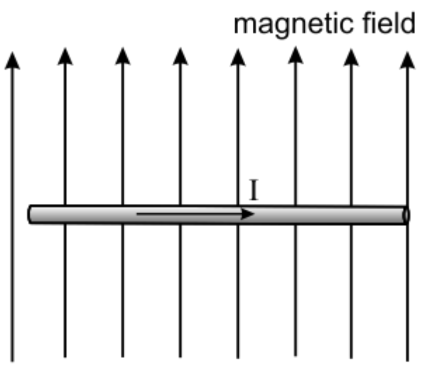
D. to the top of the page

E. to the bottom of the page

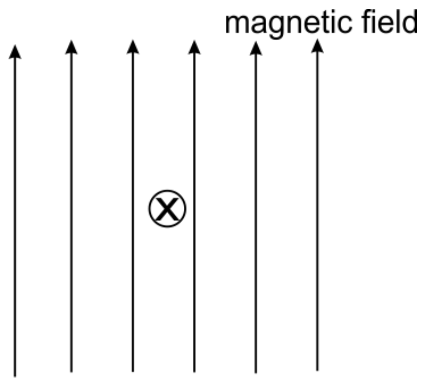
F. out of the plane of the page

G. into the plane of the page.

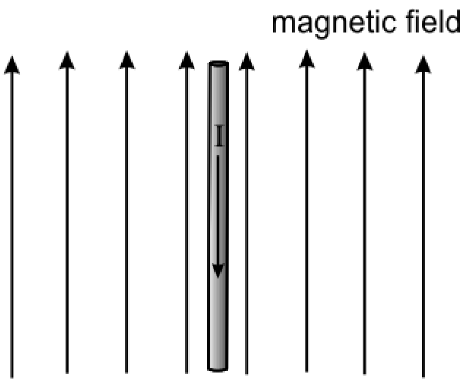
11.1



11.2



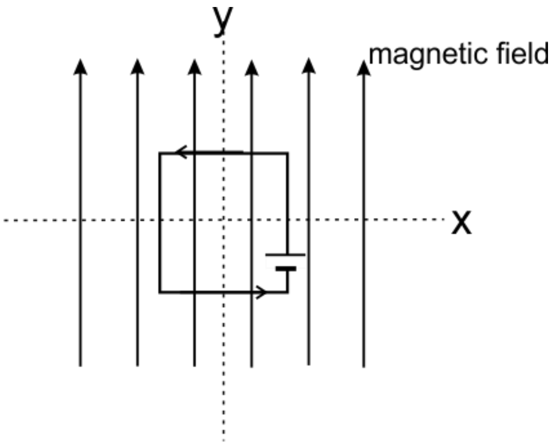
11.3



11.4

Question 12

The diagram shows a rectangular wire loop carrying current counter clockwise as shown. The loop is placed in a uniform magnetic field.



How will the loop tend to move?

A. in the direction of the magnetic field lines

B. in a direction opposite to the magnetic field lines

C. to the right

D. to the left

E. it will tend to stretch in the y-direction

F. it will tend to stretch in the x-direction

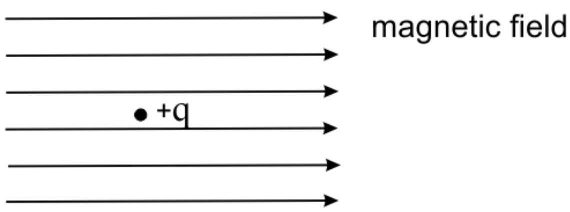
G. it will rotate about the x-axis

H. it will rotate about the y-axis

I. it will rotate about an axis perpendicular to the page.

Question 13

A particle with a positive charge is held at rest in a uniform magnetic field and then released. You can ignore the effect of gravity on the particle.



13.1 How does the particle move after it has been released?

A. The particle moves to the right with constant velocity

B. The particle moves to the left with constant velocity

C. The particle moves to the right with constant acceleration

D. The particle moves to the left with constant acceleration

E. The particle moves in a circle with constant speed

F. The particle moves in a circle with increasing speed

G. The particle stays at rest

13.2 How would you explain this?

A. There is no force on a charged particle that is stationary in a magnetic field.

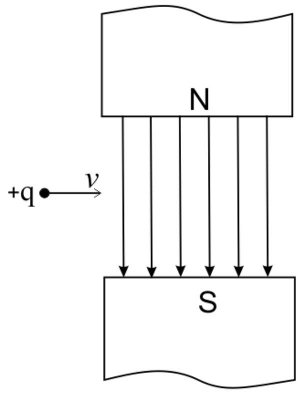
B. It experiences a constant force in the direction of the field lines.

C. It experiences a constant force opposite to the direction of the field lines.

D. It experiences a constant force at right angles to its direction of motion.

Question 14

The diagram shows a particle with a positive charge q moving with a constant speed v towards a region of uniform magnetic field.



How does the particle move when it enters the field?

A. It is deflected to the top of the page

B. It is deflected to the bottom of the page

C. It is deflected into the page

D. It is deflected out of the page

E. It slows down and stops

F. It continues moving at the same speed in the same direction

G. It slows down, stops, and then moves back in the opposite direction

Appendix G

Rubric for quantifying TSPCK as captured in a CoRe

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
A. Curricular saliency				
A0. How were key ideas selected?	- Key ideas are restricted to the headings in the CAPS document. - Key ideas include pre-concepts. - There iso evidence of attention to proper sequencing.	- Key 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 key 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 key ideas reflects the conceptual logic associated with the topic, (not necessarily using the wording of headings in the CAPS document). - Proper sequencing is evident.
A1. What do you intend learners to know about each key idea?	- Key ideas are repeated/ restated without further development into sub-ordinate ideas. - Sub-ordinate ideas were copied from the CAPS. - Identified subordinate ideas are mainly inappropriate	- Key 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 key 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.

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
A2. 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 key ideas that follow sequentially.	- 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 sequentially on the key-idea.	- 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 curriculum and in the learners' understanding of the world around them is evident.
A3.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. (refer to expert CoRe) - Concepts from other topics having logical links with the key idea are inculded.

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
A4. 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 (refer to expert CoRe). - Selected ideas indicate strategic thinking about content. -Rich content knowledge is evident.
B. What makes the topic difficult to teach				
B1. What do you consider difficult about teaching this idea?	- Knowledge about this component is not evident - Key ideas are rephrased or restated. - Broad topics without specifying the actual sub-concepts that are problematic are identified.	- An appropriate difficulty related to one of the key ideas is identified and clearly formulated.	- Appropriate difficulties for two of the key ideas are identifies and clearly formulated.	- Appropriate difficulties for all three selected key ideas are identifies and clearly formulated. - The response mentions gate keeping concepts that when not fully understood add to the difficulty of the key idea. (refer to expert CoRe)

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
C. Learner prior knowledge				
C1. 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 key 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)	Basic (2)	Developing (3)	Exemplary (4)
D. Conceptual Teaching Strategies				
D1. 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. - Use is made of macroscopic and/or symbolic representations with no linking explanatory notes. - Limited involvement of learners is evident.	- 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 encouragement of learner involvement.	- 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 centered lesson. -There is evidence that strategy will support conceptual understanding. - There is evidence of integration and creative interaction of other components.

Component prompts	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
D2. 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.
E. Representations and analogies				
E1. 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. (refer to expert CoRe) - Explanatory notes link the different kinds of representations to aspect(s) of the concepts being explained.

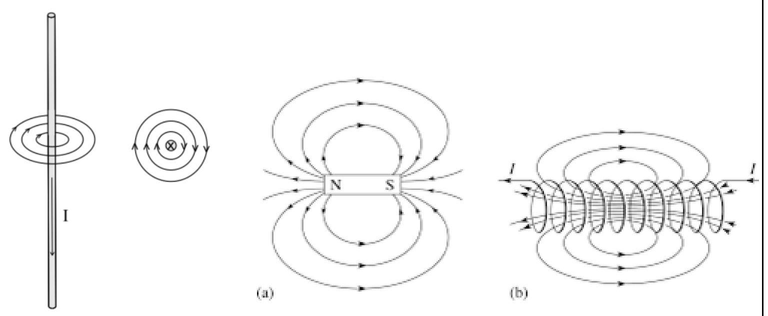
Appendix H

Expert CoRe : Electromagnetism

(Key ideas 3 and 4 follow on page 4)

Key Ideas 1 and 2	**1. A magnetic field exists around a current carrying conductor**	**2. The phenomenon of induction - the basic principle**
A1. What do you intend the learners to know about this idea?	• As soon as a current flows in a conductor, a magnetic field exists around the conductor. • The direction of the magnetic field can be determined with the right-hand rule – application to a straight conductor, loop and coil. • A coil that carries current forms an electromagnet. • Factors that determine the strength of an electromagnet	• When moving a magnet and a conductor relative to one another, a current will be induced in the conductor. • Mechanical energy is converted to electrical energy.
A2. Why is it important for students to know this?	• To be able to interpret and apply Lenz's law for determining the direction of induced current. • To be able to understand why a current-carrying conductor will experience a force in a magnetic field – electromagnetic force. (electric motors Gr 12)	• To be able to understand the necessity of developing the concept of magnetic flux as the way a magnet interacts with the conductor.
A3. What concepts need to be taught before teaching this idea?	• What a magnetic field is: the direction and shape of a magnetic field around a permanent magnet (Gr 8) • Magnetic field lines are imaginary lines that help one to visualise the direction and strength of the magnetic field. • A compass needle is a magnet. • The effect of a magnetic field on a compass needle	• Magnetic field lines are imaginary lines that help one to visualise the direction and strength of the magnetic field. • Mechanical energy and electrical energy • The concepts of current and emf
A4. What else do you know about this idea (that you do not intend learners to know yet)?	• A changing magnetic field induces a changing electric field perpendicular to the magnetic field. (Application Faraday's law and in electromagnetic waves)	• The definition of magnetic flux • Faraday's law • Lenz's law

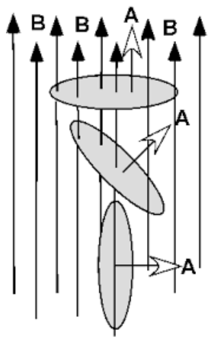
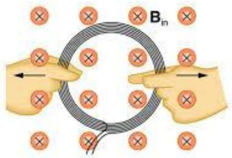
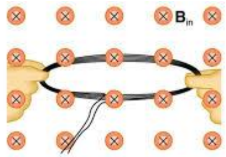
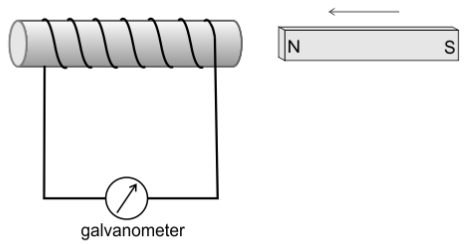
Key Ideas 1 and 2	**1. A magnetic field exists around a current carrying conductor**	**2. The phenomenon of induction - the basic principle**
	• The magnetic field around a current-carrying conductor can interact with an existing, external magnetic field to produce a force or torque on the current carrying conductor or loop.	
B1. What do you consider difficult about teaching this idea?	• The concepts do not form part of learners' everyday life experience. Their experience with magnetic fields is limited to actual permanent magnets. • Because force fields are not visible, the concept is very abstract. • Learners find it hard to understand how magnetic fields around conductors can reinforce one another in certain places and cancel one another in other places.	• The idea of induction is new to learners and it takes a while for them to grasp this fundamental concept.
C1. What are typical learners' misconceptions when teaching this idea?	• Learners believe the magnetic field around a straight conductor has a north and a south pole.	• Current will only be induced when the magnet moves and the coil is stationary.
D1. What teaching strategies would you use to teach this key idea?	• Connect a long straight wire to a power source. Place a sheet of card-board on a plane perpendicular to the long straight wire close to (or around) the wire. Use iron filings and tiny compasses on the card-board to show the existence of a magnetic field. • Determine the direction of the current in the wire by looking at the polarities of the connections to the power source – apply the right-hand rule. Compare the direction in which the fingers are pointing with the direction in which the compasses are pointing. • Repeat with a wire coil. • Learners make an electromagnet with soft iron and with steel. Pick up iron filings.	• Connect a coil to a galvanometer. Draw the learners' attention to the fact that there is no source of emf in the circuit. • Take a strong bar magnet and let a learner push it into the coil. Ask the learners about their observation regarding the galvanometer. Emphasise that current is only detected by the galvanometer when the magnet is moving (or when the coil is moving) and that the direction of the current changes when the magnet is pulled out or when the poles are reversed. • Use computer simulations such as PhET simulations showing how current is induced when there is relative motion between a magnet and a coil. .

Key Ideas 1 and 2	**1. A magnetic field exists around a current carrying conductor**	**2. The phenomenon of induction - the basic principle**
D2. What questions would you consider important to ask in your teaching strategy?	• How can one determine the presence of a magnetic field anywhere in space? – Iron filings will arrange themselves in a pattern/a compass needle will deflect. • How does a compass needle indicate the direction of a magnetic field? – The end of the needle that normally points towards the geographic north pole of the earth points into the direction of the magnetic field.	• When connecting a coil to a galvanometer, ask: What is the function of the galvanometer? • What happens when the magnet is moved relative to the coil? How is it possible for the magnet to interact with the conductor without touching it? • Which energy conversion is taking place in this situation?
E1. What representations would you use in your teaching strategy?	• A straight wire and a wire coil connected in a circuit with compass and/or iron filings needles around the wire and the coil. • The right hand rule(s) for a wire and a coil (emphasise differences) • Representing direction: cross - away from, dot - towards • Diagrams: 	• A coil connected to a galvanometer and a strong bar magnet
What ways would you use to assess learners' understanding?	• Ask learners to complete diagrams with appropriate arrows to indicate the direction of magnetic fields if the direction of the current direction in a straight wire or a coil is given.	• Ask what is required to induce current in a coil (without a power source)

Key Ideas 3 and 4	3. Magnetic flux is the total magnetic field over an area perpendicular to the field	4. Electromagnetic induction – Faraday's law
A1. What do you intend the learners to know about this idea?	• One can think of magnetic flux through a surface as the number of magnetic field lines passing through that surface. • Mathematical definition: $\phi = BAcos\theta$, where ϕ is the magnetic flux measured in weber, **B** is the magnetic field measured in tesla, **A** is the area vector perpendicular to the surface and θ is the angle between **A** and **B**. The area is often the cross-section of a coil. • Ways to change the magnetic flux through a coil.	• Changing the magnetic flux (in any possible way) through a coil will result in induced current. • The magnitude of the induced current depends on: ○ The rate of change in the magnetic flux ($\frac{\Delta\phi}{\Delta t}$) and the number of turns in the coil (N). • Faradays law: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ ○ The meaning of the negative sign • Lenz's law to determine the direction of the induced current • The relationship between the induced emf (ε)and the induced current is given by $\varepsilon = IR$ where R is the total resistance in the circuit where the current is induced. • Changing the direction of the current in the loop – generating alternating current
A2. Why is it important for students to know this?	• This idea forms the basis of Faraday's law where the rate of change of magnetic flux is an important concept.	• The concept has a practical application in the principle on which a generator operates. Generators form part of the Gr 12 curriculum. • To understand how AC current and DC currents are generated. • To understand the way transformers work.
A3. What concepts need to be taught before teaching this idea?	• Magnetic field and magnetic field lines • The vector (**A**) is perpendicular to a surface and indicates the magnitude of the area of the surface and the orientation of the surface.	• The concept of magnetic flux • Different ways in which the magnetic flux can change • Concept of induction • The relationship V=IR
A4. What else do you know about this idea (that you do not intend learners to know yet)?	• How the rate of change in magnetic flux relates to the magnitude of the induced emf. (This will be dealt with when the next key idea is explained).	• How the idea of electromagnetic induction is applied in transformers and generators.

Key Ideas **3 and 4**	**3. Magnetic flux is the total magnetic field over an area perpendicular to the field**	**4. Electromagnetic induction – Faraday's law**
B1. What do you consider difficult about teaching this idea?	• Learners have no experience or prior knowledge about the idea of magnetic flux. • Learners do not understand how a surface area can be described by a vector. • Learners' ability to visualise the vectors and angles in 3D is limited hence the inability to understand the relevance of or to determine the angles between the magnetic field and the area vector.	• Learners think of magnetic field lines as moving entities ("-it goes from north to south"), therefore they think that the mere existence of a magnetic field in a coil will result in induced current. • Learners find it difficult to apply Lenz's law and the right-hand rule to determine the direction of the induced current. • To convince learners that zero flux does not mean that the induced emf is zero. Often when the flux is zero, the rate of change of flux is a maximum and the induced emf is a maximum.
C1. What are typical learners' misconceptions when teaching this idea?	• Learners have not encountered the concept of magnetic flux preveiously and have not formed misconceptions about the concept. • They may not understand that magnetic field lines are just an imaginary pictorial aid to understand magnetic field, but magnetic flux is an actual physical quantity.	• Learners tend to think of magnetic field lines as something that moves in a certain direction, indicated by the arrows in the field. Therefore they think that a current will be induced even when the magnetic flux through a loop does not change, reasoning that the current will be induced in a direction so as to oppose the "motion" of the magnetic field lines. • Learners believe that current will only be induced when the magnet moves and the loop is stationary.
D1. What teaching strategies would you use to teach this key idea?	• Use a piece of cardboard (which depicts a particular surface) and a pencil perpendicular to the surface to explain the A-vector. • Make a loop with a thick wire. Use the light from a light source as an analogy of magnetic flux through the loop. Explain how the flux changes as the orientation of the loop changes. • Use diagrams to explain the angle between the magnetic field and the area vector. • Use computer simulations such as PhET simulations.	• Connect a coil to a galvanometer. Draw the learners' attention to the fact that there is no source of emf in the circuit. • Take a strong bar magnet and let a learner push it into the coil. Ask the learners about their observation regarding the galvanometer. Emphasise that current is only detected by the galvanometer when the magnet is moving and that the direction of the current changes when the magnet is pulled out.

Key Ideas 3 and 4	**3. Magnetic flux is the total magnetic field over an area perpendicular to the field**	**4. Electromagnetic induction – Faraday's law**
		• Ask learners to think of ways in which the magnitude of the current can be increased. Let them test their ideas with the bar magnet and the coil. • Introduce learners to the following words and phrases and relate them to the demonstrations above: ○ A change in magnetic flux induces current in the coil. ○ If the rate of change in magnetic flux is higher (the magnets move faster), the magnitude of the induced current is higher. ○ The direction of the induced current depends on the direction of the flux **and** whether it is increasing or decreasing. ○ Lenz's law • Introduce the learners to Faradays' law and relate the meanings of the symbols to the demonstrations above. • Work through example problems.
D2. What questions would you consider important to ask in your teaching strategy?	• Before suggesting ways to change the magnetic flux, ask learners to think of ways in which the magnetic flux can be changed. • When rotating the loop, changing its orientation relative to the flux, ask: ○ When is $\phi = 0$? ○ When is ϕ a maximum/a minimum? ○ When is the *rate of change* of flux a maximum/ a minimum?	• When doing the demonstration with the coil and bar magnet: ○ Is there current in the coil when the magnet is not moving? ○ How can one increase the amount of current in the coil? – Move the magnet faster, use a stronger magnet, use a coil with more turns. ○ How can one change the direction of the current induced in the oil? – Pulling the magnet out of the coil; reversing the poles of the magnet when pushing it into the coil

Key Ideas 3 and 4	3. Magnetic flux is the total magnetic field over an area perpendicular to the field	4. Electromagnetic induction – Faraday's law
E1. What representations would you use in your teaching strategy?	• A cardboard and pencil to explain the area vector and its orientation • A wire loop and light source • Diagrams: 	• A coil, galvanometer, bar magnets • Computer simulations can be shown. • Right-hand rule to determine the direction of induced current. • Diagrams such as: 
What ways would you use to assess learners' understanding?	• Give diagrams of loops or coils where a magnetic field exists. The diagrams will show different orientations of the area of the loop and the direction of the magnetic field. Ask learners to calculate the flux. • Ask learners to calculate the change in flux $\Delta\phi$, when **A**, **B** or θ changes.	• Ask learners to predict the direction of induced current when given diagrams of coils or loops, with the change in magnetic flux indicated. • Learners must solve unseen problems about Faradays' law.

Appendix I

Pre- and Post-CoRe of Student MS

Pre-CoRe Student MS

Key Idea	1. State Faraday's law.	2. Use RH rule to determine direction of induced current.	3. Calculations using Faraday's law.
A. Curricular saliency			
A1. What do you intend the learners to know about this idea? Repeat key idea.	Relationship of induced emf to rate of change of flux. (and not change of field without time).	Apply RH rule based on previous concept of the rule (on a str wire) but apply it to a solenoid.	This is an application of Faraday's law ie. using eqn based on the law to calculate ε.
A2. Why is it important for students to know this? sub-ordinate idea	~~Current~~ Induced current changes according to the change in flux → so current and magnetic fields are related	Using this rule helps to determine directions of flux and fields, which would help with calculations.	This allows learners to calculate induced emf and induced current where the magnetic field changes. (so, not just a constant magnetic field).
A3. What concepts need to be taught before teaching this idea? What knowledge should be in place?	There is a magnetic field near a current carrying wire.	Start RH rule with a straight wire, then change shape of wire (and still apply the principle of the rule).	Magnetic ~~flux~~ field is perpendicular to the flow of current ∴ one needs a B cos θ factor to only account for the vertical/perpend component and "ignore" the parallel component. correctly identified
A4. What else do you know about this idea (that you do not intend learners to know yet)? fundamental to key idea	The flux decreasing when the north pole is pulled out of a solenoid, and that the flux also changes with the relative direction in which the magnet is pushed relative to the current.	The magnetic field and current are related depending on the direction, and a factor needs to be put into the calculation to account for it, and that there is another "version" of the RH rule where three components are all perpendicular to each other	Faraday's law (eqn) can be used to explain the basic principles of an AC generator. (coil is mechanically rotated in a magnetic field). ✓

B. What makes a topic easy or difficult to understand			
B1. What do you consider difficult about teaching this idea?	-Some find it difficult to rote learn a law, while others can apply it without knowing what they are applying. -Some just learn it without knowing how to use it. -Need to get them to understand the law - so they can recite and apply it. (General)	Knowing which finger represents which component of the concept/calculation, how to apply the directions of the diff. components when solving a problem.	Learners may see it as a recipe ie just learn how to use the formula and substitute numbers without thinking about the concepts behind it, and might not be able to apply the equation in a slightly different scenario. (Vague general)
C. Learner prior knowledge			
C1. What are typical learners' misconceptions when teaching this idea?	Faraday's law involves rate of change of flux. (product of magnetic field and cross-sectional area the field lines pass through) but they might think its only the field (and not the product with the area) or they forget about rate (Δt). ✓	Left hand is still a hand and that the RH rule would still be applicable (without thinking that hands are mirror images). ✓	The negative shows direction but they might include it when calculating the magnitude of E. (Student has wrong understanding →E. is not a vector.)
D. Conceptual Teaching Strategies			
D1. What teaching strategies would you use to teach this key idea?	Combine with other laws that have been learnt (eg Snell's law, Newton's) and let the learners build a collection of flashcards c̄ the name of the law on one side, the law on the other, and the class can quiz each other. (like a game). (Unappropriate Teacher centred. Lack of conceptual teaching ideas)	Use a mirror + models to show chiral/achiral concept, then prove that LH and RH show different conclusions when applying the same rule. ✓ Relevant	Practice examples on how to apply the equation - but also tell them how to adapt the concepts when the scenario changes. (Vague no specific reference to concepts.)

D2. What questions would you consider important to ask in your teaching strategy?	To ask a learner to recite the law, and to ~~a~~ know which info relates to which component of the law. (rote learning)	They need to know that mirror images ~~are~~ exist, and that the RH rule makes life easier, and ~~#~~ I would ask them if they know which component ~~a~~ is represented by the different digits. → not relevant	They need to know Faraday's law in words, so that they know which component of the equation goes with which part of the law. (→ relates to other key idea)
E. Representations			
E1. What representations would you use in your teaching strategy?	To illustrate that there is a difference between field and flux - use two bottles of water, one of plain water and add laxatives in the other – both bottles look ~~the so~~ similar but are different (plain water = field, ~~and~~ doctored water = flux since there are other products in it) (inappropriate not conceptual)	Mirrors and models to show that the hands are different, and show that the results are very different.	To show why one needs the BcosΘ factor for the vertical component, I would use string to show that the slanted component is not the same length as a perpendicular line (ie build triangles with string to show why one needs to apply trig to get the vertical component).
Additional questions not linked to a specific component			
What ways would you use to assess learners' understanding?	Short quiz of whole class – see if they can state the different laws with words. Use diagrams with the different components labelled – and see if they can match the components with the words in the law.	Do worksheet with diagrams where they need to label the (mean) direction of the current/field with some information given.	Worksheet – with calculations for the learners to get the calculated answer, and some questions would be where the answer would be given, but it would be wrong and the learner would need to "correct" it or explain why it is incorrect. And some questions would have the scenarios changed slightly, while others would be the same as the class example, with the values/picture changed.
What aspects of teaching and planning for this big idea would you like to reflect on?	There isn't much teaching in this idea – it's mostly rote learning, so there should be other ways of making them understand the law. (reveals misunderstanding / complete of concept)	Some learners would be bored since they would understand the concept – so there needs to be other ways to keep the bored learners entertained for a while.	The worksheet may not be the best tool for all learners. The time needed might be too long – esp if it becomes a trig lesson.

post-CoRe Student MS

Write all the key ideas in the topic Electromagnetism grade 11. Write them in the sequence you will teach them. Write as many key ideas as you seem fit for teaching this topic.

- Current carrying wire has a surrounding magnetic field → so does a loop and a solenoid.
- Use the RH rule to "see" the direction of the magnetic field and draw it on paper.
- Using real life examples, relate how electromagnets can be made and that the reverse also happens -- but (reverse being magnet inducing ~~so~~ a current). only when the magnet moves.
- Use RH rule to determine direction of current.
- Introduce magnetic flux and how that changes according to $BA \cos\theta$, and how one can change magnetic flux.
- Give a name (Faraday's law) to the induced current.
- Introduce torque and $F = qvB$. (in prep for Gr. 12).

Choose three of the key ideas mentioned above and complete the CoRes below.

Key Idea	1. Current carrying wire has a surrounding magnetic field	2. Current can be induced by a moving magnet	3. Magnetic flux
A. Curricular saliency			
A1. What do you intend the learners to know about this idea?	A current carrying wire has a specific magnetic field in a direction that is specific to the direction of the current - and that it ~~happe~~ exists whether it is a straight wire, loop or many loops.	A moving magnet in a solenoid/wire loop can induce a current in the wire.	The "moving" magnet" causes something called ~~and~~ magnetic flux - and this is what causes the current, not the actual movement of the magnet per se.

A2. Why is it important for students to know this?	This knowledge gets built up-it serves as an "intro" to the relationship ~~w~~ between electric current and magnets and how current can be induced.	The induced current is how electricity is made (in a nutshell), and this would build up to generators in Gr. 12 ~~m~~	Magnetic flux can determine how much current can be induced, ~~to~~ and that there are different ways to change it (not just adding magnets to increase strength)
A3. What concepts need to be taught before teaching this idea? What knowledge should be in place?	Magnetic field has a distinct pattern and has a specific direction.	~~Wires~~ Current can cause a magnetic fields around the wire, ~~and a magnet would cause a current to~~ like poles repel each other.	Magnetic fields around magnets, surface area (maths) angles (from maths)
A4. What else do you know about this idea (that you do not intend learners to know yet)?	Current can be induced by a magnet (where there is a change in magnetic flux)	The magnets movement causes magnetic flux, which is what causes the current, and this is how generators generate electricity (Gr. 12)	Faraday's law sums up the relationship between magnetic flux and the induced emf.

B. What makes a topic easy or difficult to understand			
B1. What do you consider difficult about teaching this idea?	Current deals with charges, magnetic fields are not charges, yet the two "things" are related. ~~to that~~ Also, the direction can get confusing with the more loopy wires.	Determining the direction of the current (as shown by the galvonometer), and applying the RH rule in a different way to determine the direction of the current.	To picture the changes in magnetic flux being due to different possible factors - and the angle θ that needs to be relative to the normal and ~~not from~~ of the relative surface and not the actual surface.
C. Learner prior knowledge			
C1. What are typical learners' misconceptions when teaching this idea?	Magnetic fields are caused by charges, charges cause electricity, that's the reason for the current-carrying wire causing a magnetic field.	- Current ~~is~~ is just a current and there needs to be a power source. - Direction of a current doesn't change ~~depending~~ (current can only flow in a certain direction) - Immobile magnets can cause a current (since immobile magnets have a magnetic field too)	- magnetic flux is only changed by the strength of the magnetic field and not by the relative angle (to the normal) of the surface. - a ~~stationary magnet~~ ~~can~~ still - ~~movem~~ flux changes when the magnet is stationary (even if the other factors remain the same).

D. Conceptual Teaching Strategies			
D1. What teaching strategies would you use to teach this key idea?	Investigation and direct. Inv: show them with a current carrying wire and iron filings/compass that there is a magnetic field Direct teaching: Tell them that they can use their RH to work out the direction of the magnetic field.	Demonstration with a solenoid, a magnet and a ~~ga~~ light bulb then galvonometer.	Demonstration using sticks (as magnetic field), ~~a~~ malleable rings with cling wrap on it (same sized ring with different surface areas) E. Representations - poke holes through the cling wrap using the magnetic field sticks - the ~~a~~ holes represent flux. Repeat ~~a~~ with different surface areas, different angles and different magnetic field strengths - and see how the number of holes changes.
D2. What questions would you consider important to ask in your teaching strategy?	- What they think could happen to the iron filings. - Why do the compasses move - What do the compasses tell us about the direction of the field.	- Why does the light bulb light up? - Why does the needle on the galvonometer change direction?	- Which ring/surface area would have the most ~~sk~~ sticks poking holes through - Which angle would have the most holes - What factors changes the number of holes?

E. Representations			
E1. What representations would you use in your teaching strategy?	Demo: magnetic field around a wire shown by iron filings / compasses. RH rule: link the direction of the magnetic field to the RH rule and let them all try it.	Using an experimental set-up, show that a moving magnet would cause the bulb to light up, then use the galvonometer to show the swinging needle (that shows direction of current).	Oops - I wrote it under D1 already (got carried away)
Additional questions not linked to a specific component			
What ways would you use to assess learners' understanding? What aspects of teaching and planning for this big idea would you like to reflect on?	Give them ~~two~~ two questions showing the direction of the current / the magnetic field, and the learners would need to write down the direction of the magnetic field / current and they need to show it to me / or to their neighbour. I ~~would~~ should actually add more "types" of wires (loops) to build up to the solenoid and the magnetic field around a solenoid.	Ask them verbally to predict if current would be induced in certain scenarios then show them. (and let them write down the answers) (eg. when a magnet is stationary or if a magnet moves in a different direction). The testing of the knowledge needs a better way than a worksheet to check if they can re-write what was shown - verbal responses are not ideal as it doesn't check the knowledge of all the learners.	Worksheet with practice questions on calculating magnetic flux. The representation - there should be something else that could show magnetic flux just as efficiently, but requiring less prep.

Appendix J

Pre- and Post-Core of Student LM

Pre-CoRe Student LM

Key Idea	1. The Right Hand Rule	2. Faraday's Law.	3. Induced current
A. Curricular saliency			
A1. What do you intend the learners to know about this idea?	That with the right hand rule you can be able to determine direction to all posible component involved in your system.	that the electromotive force is related to the change of flux.	to know that charges and thus current can be induced by ~~a~~ magnetic fields.
A2. Why is it important for students to know this?	because you can determine any unknown from the right hand rule, be it the direction of current, magnetic field or Force.	~~because they can~~ deter because if they know the emf they can easily calculate the flux.	because it is important in understand how a generator works.
A3. What concepts need to be taught before teaching this idea? What knowledge should be in place?	the existence of magnetic field near a current carrying wire.	the emf, cross-sectional area	that flowing current ~~charges can be induced~~ produces magnetic fields
A4. What else do you know about this idea (that you do not intend learners to know yet)?	I know there is another form of the right hand rule which doesn't involve the palm, the don't have to know it yet.	that Faraday's ~~law doesn't~~ ~~a~~ law isn't always valid thus maxwell made some modifications to it to make it valid across all borders	that Induced current is ~~[illegible]~~ permanent and ~~that~~ if ~~ab~~ you take away the magnetic field it ~~also you loose it as well~~ creates a magnetic field to oppose the change.

B. What makes a topic easy or difficult to understand			
B1. What do you consider difficult about teaching this idea?			
C. Learner prior knowledge			
C1. What are typical learners' misconceptions when teaching this idea?	that if you are left handed you ~~have~~ to use ~~your left~~ can use your left hand and still get the correct answers.		that since the induced current is produced by the magnetic field, if you remove the field the induced current disappeares.
D. Conceptual Teaching Strategies			
D1. What teaching strategies would you use to teach this key idea?	direct teaching strategy.		

D2. What questions would you consider important to ask in your teaching strategy?			
E. Representations			
E1. What representations would you use in your teaching strategy?	the right hand and drawings.	Simulation or a practical demonstration	Simulation.
Additional questions not linked to a specific component			
What ways would you use to assess learners' understanding? What aspects of teaching and planning for this big idea would you like to reflect on?	giving them a diagram and asking them to identify the directions of current, magnetic field, ...		give the misconception tests on the work covered to test if all the ~~iden~~ misconceptions were addressed.

post-CoRe Student LM

Write all the key ideas in the topic Electromagnetism grade 11. Write them in the sequence you will teach them. Write as many key ideas as you seem fit for teaching this topic.

Magnetic field associated with current carrying wire, The direction of magnetic field in ~~the~~ a current carrying wire, Drawing magnetic fields around current carring wire, Magnetic flux, ~~Faraday's law~~ induced emf

Choose three of the key ideas mentioned above and complete the CoRes below.

Key Idea	1. Magnetic field of current carrying wire	2. Magnetic flux	3. Induced emf.
A. Curricular saliency			
A1. What do you intend the learners to know about this idea?	That because moving charged particles have ~~an~~ a magnetic field associated to them and an electron being an example of a charged particle that carries electric charges in a current carrying wire we have that a current carrying wire has a magnetic field associated to it. Since current is the flow (move) of electron across a cross-section of a wire	That the magnetic flux passing through a loop is defined as: $\phi = BA\cos\theta$ and that it is dependent on the area of the loop, the strength of the uniform magnet field and the angle between the magnetic field and the normal to the area of the loop.	that in the presence of a magnetic field an emf is ~~ed~~ induced over time and it changes with ~~the strength of a the magnetic field~~, change in magnetic flux and the number of turns in the coil.

A2. Why is it important for students to know this?	Because they need to know about Magnetic fields associated with current carrying wires to understand how motors work.	Because the magnetic flux is important in determining the emf	It's important because Students need this to understand how generators work.
A3. What concepts need to be taught before teaching this idea? What knowledge should be in place?	→ The magnetic field around a bar magnet (magnetic fields in general), they need to know that an electron is a charged particle and that moving ~~pa~~ charged Particle have magnetic fields.	Area of a circle, Rectangle, Square and other shapes → the magnetic field → the dot product.	→ magnetic flux → types of wires → Magnetic ~~the~~ fields → how you create a Solenoid
A4. What else do you know about this idea (that you do not intend learners to know yet)?	→ that the reverse of this Idea is applicable, where magnetic fields Induce current.	→ ~~There is an induced current~~ there is a magnetic field induced by the current that oppose the change in magnetic flux	→ that you can use it to explain why a current is induced in a coil that is rotated in a magnetic field.

B. What makes a topic easy or difficult to understand			
B1. What do you consider difficult about teaching this idea?	The availability of necessary resources to demonstrate to the learners that indeed there is a magnetic field associated with a current carrying wire.	there is nothing difficult to teach about the idea.	Demontrating the idea in a way that learners would understand the content is difficult.
C. Learner prior knowledge			
C1. What are typical learners' misconceptions when teaching this idea?	That since the magnetic field around ~~a current~~ Magnet is permenant so will the magnetic field around a ~~current~~ wire, this however can be addressed by the use of demonstrations.	Misconception created by the Drawings where you draw a ~~fie~~ few magnetic field and more in another drawing, the learners ~~the~~ tend to think that how magnetic fields ~~are~~ present, when there a lot all over space ~~and~~	The learners think that induced emf is related to magnetic flux (magnetic flux is always constant) ~~Instead of~~ over time instead of the change in magnetic flux over a period of time.

). Conceptual Teaching Strategies			
)1. What teaching strategies would you use to teach this key idea?	• Inquiry or discovery. → group-work → discussion	→ Direct instruction → Inquiry or discovery.	→ Direct instruction → Inquiry or discovery → group-work.
)2. What questions would you consider important to ask in your teaching strategy?	→ why do compasses respond ~~to~~ when you switch on the power for current to flow in a wire? → why is there such a presence around a current carrying wire.	→ How does the magnetic flux change when you change the ~~are~~ shape of the loop?	→ How can one change the emf.? → what is an emf?

E. Representations			
E1. What representations would you use in your teaching strategy?	Demonstrations, Drawings -> do an experiement that shows that indeed there is a magnetic field around a current carrying wire.	Simulations, drawings and demonstrations.	Simulations, videos and pictures
Additional questions not linked to a specific component			
What ways would you use to assess learners' understanding? What aspects of teaching and planning for this big idea would you like to reflect on?	-> Give them a conceptual worksheet to complete	-> Ask the to write down everything they understand about magnetic flux and submit it at the end of the class.	-> Give them a worksheet to compete at the end of the lesson.

Appendix K

Calculation of the inter-rater reliability (Fleiss' kappa)

The pre- and post-CoRes of four students were scored by three scorers.
The number of scorers that assigned a particular level for that particular prompt is indicated in the columns.

Item	limited(1)	Basic(2)	Developing(3)	Exemplary(4)		
A0		3			1	Pre-CoRe Student 1
A1		3			1	
A2		3			1	
A3	2	1			0.333333	
A4	2	1			0.333333	
B1		3			1	
C1		3			1	
D1		3			1	
D2		3			1	
E1	3				1	
A0		3			1	Pre-CoRe Student 2
A1		3			1	
A2		3			1	
A3		2	1		0.333333	
A4	3				1	
B1	1	2			0.333333	
C1		3			1	
D1	1	2			0.333333	
D2		3			1	
E1		3			1	
A0		3			1	Pre-CoRe Student 3
A1		3			1	
A2		3			1	
A3	2	1			0.333333	
A4	2	1			0.333333	
B1		2	1		0.333333	
C1	3				1	
D1	3				1	
D2		3			1	
E1		3			1	
A0	3				1	Pre-CoRe Student 4
A1		3			1	
A2		3			1	
A3		3			1	
A4		2	1		0.333333	
B1		2	1		0.333333	
C1		3			1	

Item	limited(1)	Basic(2)	Developing(3)	Exemplary(4)		
D1	2	1			0.333333	
D2		3			1	
E1		3			1	
A0			3		1	Post-CoRe Student 1
A1			3		1	
A2			2	1	0.333333	
A3			3		1	
A4			3		1	
B1		1	2		0.333333	
C1			3		1	
D1			3		1	
D2		1	2		0.333333	
E1		3			1	
A0			3		1	Post-CoRe Student 2
A1			3		1	
A2			3		1	
A3			2	1	0.333333	
A4	1	2			0.333333	
B1		3			1	
C1			3		1	
D1			3		1	
D2			2	1	0.333333	
E1			3		1	
A0			3		1	Post-CoRe Student 3
A1		2	1		0.333333	
A2	2	1			0.333333	
A3			3		1	
A4		2	1		0.333333	
B1		3			1	
C1			3		1	
D1		3			1	
D2			3		1	
E1		3			1	
A0		3			1	Post-CoRe Student 4
A1		3			1	
A2	2	1			0.333333	
A3		3			1	
A4		3			1	
B1	2	1			0.333333	
C1		1	2		0.333333	
D1	3				1	
D2		3			1	
E1			3		1	
	37	131	69	3		

Item	limited(1)	Basic(2)	Developing(3)	Exemplary(4)	
	0.154166667	0.545833333	0.2875	0.0125	
	average	0.808333333			
	pe	0.404513889			
	Fleiss' kappa	0.678134111			

Appendix L

Rubric for assessing TSPCK as enacted during the teaching of electromagnetism

Components	Restricted	Adequate	Rich
Curricular saliency	• Never elicits learners' knowledge of pre-concepts • Does not show evidence of knowledge of scaffolding of concepts • No logical sequencing of concepts evident – "jumping around"	• Elicits knowledge of some of the pre-concepts, but assumes knowledge of others • Sequencing of concepts is logical, but omits out important ideas.	• Elicits knowledge of all applicable pre-concepts at appropriate phases in the lesson • Shows awareness of the scaffolding of concepts in the topic by referring to pre- or forthcoming ideas • Reminds learners of pre-concepts when these are applicable in the conceptualisation of new ideas. • Teaches key ideas and sub-ordinate ideas with logical sequencing
What makes the topic difficult to teach?	• Does not pay attention to typical difficulties that can arise • Shows no evidence of techniques to address difficulties	• Mainly uses repetition (without changing the approach) to address learner difficulties. • Misses some indications that learners find a concept difficult to understand.	• Breaks down difficult ideas into understandable units that are sequenced logically • Pays attention to possible misinterpretations such as the meaning of "opposed to" in Lenz's law. • Uses techniques such as "slowing down", repetition and a different approach to address learner difficulties.
Learner prior knowledge	• Knowledge of learner thinking not evident • Does not pay attention to possible existing misconceptions (e.g. confusion between magnetic poles and charges) • Own misinterpretations and misconceptions are evident	• Pays attention to some known misconceptions. • Misses some opportunities to address possible misconceptions.	• Pays attention to all (or most) known misconceptions. • Knowledge of learner thinking evident. • Responds to and addresses gaps in knowledge of pre-concepts. • Uses analogies from learners' world to explain ideas

Representations	• Relies mostly on explaining and telling. • The use of representations is restricted to drawings also available in textbooks.	• Use of representations restricted to one type of representation only. • Uses objects as illustrations or artefacts. • Uses a representation with no apparent conceptual development in learners.	• Makes extensive use of representations in combination, e.g. videos and diagrams or demonstrations and diagrams • Uses representations to support understanding of concepts • Uses representations effectively to stimulate conceptual reasoning
Conceptual teaching strategies	• Questions elicits chorus or yes/no responses. • Answers own questions before learners make an attempt. • Ignores learners' answers when not in line with the expected answer. • Does not show awareness when learners reveal the existence of misconceptions • Does not make an effort to incorporate representations to support conceptual understanding.	• Questions asked mostly requires rote learning • Answers own questions after only one or two attempts by learners – does not rephrase questions. • Addresses misconceptions through procedural teaching. • Uses representations in combination with direct instruction – telling learners what they are supposed to see or as confirmation of theory only.	• Shows an attempt to work towards problem-solving and inquiry • Asks questions to elicit learner thinking that requires conceptual reasoning • Shows creative interaction of pre-concepts. • Shows awareness of typical learner errors and misconceptions and works towards conceptual change. • Uses a variety of representations with logical sequencing in combination with appropriate question. • Waits for responses and does not answer own questions; rephrases questions.

Appendix M

Semi-structured interview schedule

1. You have had a few weeks of teaching experience while you were doing your teaching practice. What, after this exposure to teaching, do you believe is your role as a teacher?
2. To how many grade 11 classes did you teach the topic of electromagnetism?
3. Approximately how many hours did you spend on this topic (per class)?
4. How would you classify the school where you did your teaching practice - well resourced, medium resourced or under resourced? Why do you say so?
5. Describe the kind of support that you received form your mentor teacher. Is there any kind of support from your mentor teacher that you would have appreciated, but did not necessarily get?
6. If you think about grade 11- electromagnetism, what do you consider the most important concepts that should be taught?
7. In what sequence will your teach these concepts? Why? (*If the participant gives a sequence different from the sequence prescribed in CAPS, probing questions will be asked to determine the rationale behind their decision*)
8. Are there any concepts in this topic that you found particularly difficult to understand when you were first studying it? Which?
9. Which ideas in electromagnetism did you find most difficult to teach? Why?
10. Which typical learner mistakes and difficulties did you come across while teaching this topic?
11. When you were teaching a difficult concept, how did you decide that learners understand and that time was ready to move on the next concept? What evidence were you looking for?
12. Think about your teaching of electromagnetism in terms of: your sequencing of the concepts, the representations you used, the experiments or demonstrations you did and the strategy you followed to teach the concepts. In retrospect, what worked well? What do you plan to do differently when you teach this again?
13. Think back about the Physics methodology module you did in the first term of this year. Are there any aspects that were addressed during this module that you consciously and explicitly used in your teaching of electromagnetism to the grade 11's? Please elaborate.
14. Is there anything else regarding your experience teaching this topic that you would like to mention?

Appendix N

Letters of permission or approval

Approval from the GDE

For administrative use only:
Reference no: D2017 / 109
enquiries: Diane Buntting 011 843 6503

GAUTENG PROVINCE

EDUCATION

REPUBLIC OF SOUTH AFRICA

GDE RESEARCH APPROVAL LETTER

Date:	13 June 2016
Validity of Research Approval:	13 June 2016 to 30 September 2016
Name of Researcher:	Coetzee C.
Address of Researcher:	2 Trevor Street; Meyerspark; Pretoria; 0184
Telephone I Fax Number's:	012 803 3666; 083 280 8617
Emall address:	corene.coetzee@up.ac.za
Research Topic:	Pre-service teachers' development of PCK in electromagnetism
Number and type of schools:	FOUR Secondary schools
District/s/HO	Tshwane South

Re: Approval in Respect of Request to Conduct Research

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

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

CONDITIONS FOR CONDUCTING RESEARCH IN GDE

1. The District/Head Office Senior Manager/s concerned, the Principal/s and the chairperson/s of the School Governing Body (SGB.) must be presented with a copy of this letter.
2. The Researcher will make every effort to obtain the goodwill and co-operation of the GDE District officials, principals, SGBs, teachers, parents and learners involved. Participation s voluntary and additional remuneration will not be paid;
3. Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal and/or Director must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.

2016/06/14

4. Research may only commence from the second week of February and must be concluded by the end of the THIRD quarter of the academic year. If incomplete, an amended Research Approval letter may be requested to conduct research in the following year.
5. Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.
6. It is the researcher's responsibility to obtain written consent from the SGB/s; principal/s, educator/s, parents and learners, as applicable, before commencing with research.
7. The researcher is responsible for supplying and utilizing his,fier own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institution/s, staff and/or the office/s visited for supplying such resources.
8. The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not auear in the research title, report or summary.
9. On completion of the study the researcher must supply the Director: Education Research and Knowledge Management, with electronic copies of the Research Report, Thesis, Dissertation as well as a Research Summary (on the GDE Summary template). Failure to submit your Research Report, Thesis, Dissertation and Research Summary on completion of your studies / project — a month after graduation or project completion - may result in permission being withheld from you and your Supervisor in future.
10. The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned;
11. Should the researcher have been involved with research at a school and/or a district/head office level, the Director/s and school/s concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.

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

Kind regards

....

Dr David Makhado

Director: Education Research and Knowledge Management

DATE: 2016/06/04

2

Making education a societal priority

Office of the Director: Education Research and Knowledge Management ER&KM)

9th Floor, 1 1 1 Commissioner Street, Johannesburg, 2001

Letter of permission from the Dean

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education
Office of the Dean

17 September 20 5

Ms Coréne Coetzee

Department of Science, Mathematics and Technology Education

Dear Ms Coetzee

REQUEST FOR RESEARCH WITH STUDENTS

Your request to conduct research with students for your project titled, Pre-service teachers' development of PCK in electromagnetism as explained in your correspondence on 15 September 2015 refers.

Permission to conduct the study is granted.

This research project focuses on an important field and wish you all the best on the completion of the study.

Kind regards

Prof Irma Eloff
Dean of Education

Ethics approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Fakulteit Opvoedkunde
Lefapha la Thuto

Ethics Committee

11 December 2015

Dear Mrs Coetzee,

REFERENCE: SM 15/11/01

Your application was considered by the Faculty of Education Ethics Committee and the final decision of the Ethics Committee is:

Your application is approved.

This letter serves as notification that you may continue with your fieldwork. Should any changes to the study occur after approval was given, it is your responsibility to notify the Ethics Committee immediately.

Please note that you have to fulfil the conditions specified in this letter from the Faculty of Education Research Ethics Committee. The conditions include;

1) The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment (Section E) for approval by the Committee.
   - Any amendments to this approved protocol need to be submitted to the Ethics Committee for review prior to data collection. Non-compliance implies that the Committee's approval is null and void.
   - Final data collection protocols and supporting evidence (e.g.: questionnaires, interview schedules, observation schedules) have to be submitted to the Ethics Committee before they are used for data collection.

2) The researcher should please note that this decision covers the entire research process, until completion of the study report, and not only the days that data will be collected.

3) Should your research be conducted in schools, please note that you have to submit proof of how you adhered to the Department of Basic Education (DBE) policy for research.

4) The Ethics Committee of the Faculty of Education does not accept any liability for research misconduct, of whatsoever nature, committed by the researcher(s) in the implementation of the approved protocol.

Please note that this is **not a clearance certificate**.

Upon completion of your research you need to submit the following documentation to the Ethics Committee:

- **Integrated Declarations Form (Form D08),**
- **Initial Ethics Approval letter and,**
- **Approval of Title.**

On receipt of the above-mentioned documents you will be issued a clearance certificate. Please quote the reference number: **SM 15/11/01** in any communication with the Ethics Committee.

Best wishes,

Prof Liesel Ebersöhn

Chair: Ethics Committee

Faculty of Education

Appendix P

Letters requesting informed consent

Letter to the student participant

February 2016

Dear JMN433 student

Invitation to participate in a research project

I am undertaking a research study titled **Pre-service teachers' development of PCK in electromagnetism.** In this study I investigate the role the training of BEd students plays in the development of their Pedagogical Content Knowledge (PCK). This construct forms an important part of the knowledge a teacher has, since it is the amalgam of the content knowledge and the pedagogy of a teacher and distinguishes the teacher from the subject specialist. The development and improvement of this knowledge starts and is addressed during the pre-service training of a teacher. Research has established that PCK can only be developed in context of a specific curriculum topic. When PCK is well developed in one topic, teachers are able to transfer the knowledge to the teaching of other topics.

In the University of Pretoria's BEd programme, the development of PCK is directly addressed during methodology classes and Teaching Practice. In my study I would like to investigate the impact these two modules have on the development of the PCK of pre-service Physical Science teachers.

The research process is described below.

- The JMN433 physics methodology module will be adapted to focus explicitly on the five components of PCK in the topic of electromagnetism and will be taught during the first term of 2016.
- Students will be assessed at various stages on their level of content knowledge about electromagnetism.
- Students will be required to complete a PCK-assessment instrument (CoRe) for key ideas in the topic of electromagnetism at different stages. These CoRes will be scored using a rubric. The scores will count toward the module mark.
- Students will be required to present micro-lessons on the topic to their peers. The micro lessons will be assessed and will count towards the final module mark.
- During their teaching practice period students will be observed and assessed while teaching key ideas in electromagnetism.
- Students will be interviewed after their lesson presentations.

Students who participate in the study will be expected to agree to the following:

- To sign a letter of informed consent in which they agree to participate in the study.
- That the outcomes of all the assessments may be used as data for research purposes.

- That two lessons on electromagnetism taught at the schools during their teaching practice will be video recorded.
- To be interviewed by the researcher after each lesson observation.
- To obtain signed letters of informed consent from parents of the learners and the learners who will be present in the class during video recordings. These letters will be provided by the researcher.
- That all data collected may be made available in an open repository for public and scientific use, but the identity of all persons and institutions involved will be kept anonymous.

Participation in this research is voluntary. You have the right to decline the invitation to participate in the research without any consequences. Your decision to accept or decline this invitation will have no adverse effect on your training or your final mark for JMN433 or your teaching practice module. Students who do not participate will undergo the same training and assessment as the participants, but none of the outcomes will be used as data.

Yours sincerely

Mrs. Corene Coetzee
Researcher

Date: 28 April 2016

Prof. Marissa Rollnick
Supervisor
WITS University

Date: 28 April 2016

Date: 28 April 2016

Dr. E Gaigher
Co-supervisor
University of Pretoria

Prof Gerrit Stols
Head of Department
Science, Mathematics and Technology Education
Faculty of Education
University of Pretoria

Date: 28 April 2016

<u>Declaration of informed consent by students</u>

Research study: **Pre-service teachers' development of PCK in electromagnetism**

If you are willing to participate in this study, please sign this letter as a declaration of your consent, i.e. that you participate in this project willingly and that you understand that you may withdraw from the research project at any time. Under no circumstances will the identity of participants be made known in documents or communications related to this research project.

Declaration:

I have read and understood the information contained in this letter, and I voluntarily agree to participate in the described research project. I agree to the following: (Please circle your response)

To allow the researcher to use the outcomes of all my JMN433 assessments as data
Yes/No

To video record two of my science lessons on electromagnetism;

Yes/No

To be interviewed after each of the lessons observations;

Yes/No

I understand that I may withdraw from the study at any time without any adverse effects, that the data collected with public finding may be made available in an open repository for public and scientific use and that my identity will be protected at all times.

Student's name: ____________________________

Student's signature: _________________________ Date: _________________

Letter to the principle and School Governing Body (SGB)

28 April 2016

To the Principal and SGB

Dear Dr/Mr /Ms …………

E: Request to allow the video recording of the lessons of fourth year UP students at your school.

I am currently registered for a PhD study at the University of Pretoria in the Faculty of Education.

In my study titled *Pre-service teachers' development of PCK in electromagnetism* I am investigating the role the training of BEd students plays in the development of their Pedagogical Content Knowledge (PCK). This construct forms an important part of the knowledge a teacher has, since it is the combination of the content knowledge and the pedagogy of a teacher and distinguishes the teacher from the subject specialist. The development and improvement of this knowledge starts and is addressed during the pre-service training of a teacher. Research has established that PCK can only be developed in the context of a specific curriculum topic. When PCK is well developed in one topic, teachers are able to transfer the knowledge to the teaching of other topics.

In the University of Pretoria's BEd programme, the development of PCK is directly addressed during methodology classes and teaching practice. In my study I investigate the impact these two modules have on the development of the PCK of the pre-service Physical Science teachers. Students participating in this study are final year BEd (FET) Natural sciences students specialising in Physical Sciences teaching.

To accomplish this goal I intend to do the following:

- Assess the level of the PCK of the students at the beginning of their fourth year and at intermittent stages during the year. I will use an instrument that has been developed by other researchers in the field to capture the PCK of individuals for a specific curriculum topic.
- Observe, video record and interview the students during their teaching practice period at schools to establish to what extent they are able to translate the acquired knowledge into practice. These observations and video recordings will take place during the normally scheduled "crit lessons" that are arranged by the students. I will adhere to the requirements and principles of ethical conduct during these activities.

I hereby request your assistance to arrange, in collaboration with the Teaching Practice coordinator at your school, to place the participating student (*students' name*) at a mentor teacher teaching grade 11 Physical Sciences.

I also request permission to do video recordings of two lessons of the participating student. The faces of learners present in the class will not be captured on video camera and no data will directly be obtained from the learners or the mentor teachers.

Your decision to accept or decline this invitation will **not** have any adverse effect on the school, yourself, the educators, the students or learners. Should you accept this request, anonymity and confidentiality will be guaranteed at all times. Your name, the name of the mentor teachers and that of your school will not be disclosed to anyone. The information collected during the research will be used for research purposes only. All data collected with public finding may be made available in an open repository for public and scientific use, but the identity of all persons and institutions involved will be kept anonymous.

We would greatly appreciate it if you would consent to this request because data information obtained from the participating student will contribute to our understanding of the development of the Pedagogical Content Knowledge of pre-service teachers and will inform the training of education students.

If you are willing to allow me to do the video recordings and to allow the student(s) to participate in the research while doing his/her teaching practice term at you school, please kindly sign the attached form as a declaration of your consent. Thank you for taking time to read this letter.

Yours faithfully

Mrs C Coetzee — Date: 28/04/2016
Researcher

Prof. Marissa Rollnick — Date: 28 April 2016
Supervisor
WITS University

Dr. E Gaigher — Date: 28 April 2016.
Co-supervisor
University of Pretoria

Prof Gerrit Stols Date: 28 April 2016
Head of Department
Science, Mathematics and Technology Education
Faculty of Education
University of Pretoria

Declaration of informed consent by principals

Research project: *Pre-service teachers' development of PCK in electromagnetism.*

I the undersigned, has read and understood your intentions, and I hereby grant consent to the researcher to observe and video record two science lessons of the final year students at my school.

Name of School……………………………………………………………………………………

Principal's name ………………………………………………………………………..

Principal's signature……………………………… Date: …………………………

E-mail address …………………………………………… Contact number ……………...

School stamp

Signature: .... Date: ....

Mrs. C. Coetzee (researcher)

Lecturer

Faculty of Education

University of Pretoria

Letter to the mentor teacher

28 April 2016

To the mentor teacher of ………………………………..

Dear Dr/Mr/ Ms ……………………………

RE: Request to allow the video recording of the lessons of fourth year UP students.

I am currently registered for a PhD study at the University of Pretoria in the Faculty of Education.

In my study titled *Pre-service teachers' development of PCK in electromagnetism* I am investigating the role the training of BEd students plays in the development of their Pedagogical Content Knowledge (PCK). This construct forms an important part of the knowledge a teacher has, since it is the amalgam of the content knowledge and knowledge about teaching and distinguishes the teacher from the subject specialist. In the University of Pretoria's BEd programme, the development of PCK is directly addressed during methodology classes and teaching practice. In my study I investigate the impact these two modules have on the development of the PCK of the pre-service Physical Science teachers.

To accomplish this goal I plan to observe, video record and interview the students during their teaching practice period at schools. These observations and video recordings will take place during the normally scheduled "crit lessons" that are arranged by the students, when teaching electromagnetism to grade 11 learners. I will adhere to the requirements and principles of ethical conduct during these activities.

I hereby request your consent to do video recordings of two lessons of each of the participating students when teaching **electromagnetism to a Grade 11 class**. The faces of learners present in the class will not be captured on video camera and no data will directly be obtained from the learners or from you as the mentor teacher.

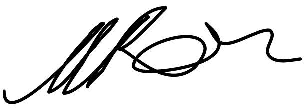
Your decision to accept or decline this invitation will **not** have any adverse effect on the school, yourself, the students or learners. Should you accept this request, anonymity and confidentiality will be guaranteed at all times. Your name, the name of the student and that of your school will not be disclosed to anyone. The information collected during the research will be used for research purposes only. All data collected may be made available in an open repository for public and scientific use, but the identity of every person and institution involved will be kept anonymous.

We would greatly appreciate it if you would consent to this request because information obtained from the participating student will contribute to our understanding of the development of the Pedagogical Content Knowledge of pre-service teachers and will inform the training of education students.

Yours faithfully

Mrs C Coetzee Date: 28/04/2016

Researcher



Prof. Marissa Rollnick Date: 28/04/2016

Supervisor

WITS University

Date: 28/04/2016

Dr. E Gaigher

Co-supervisor

University of Pretoria

Declaration of informed consent by mentor teachers

Research project*: Pre-service teachers' development of PCK in electromagnetism.*

I the undersigned, has read and understood your intentions, and I hereby grant consent to the researcher to observe and video record two lessons on **electromagnetism** taught by a final year BEd student to a **Grade 11 Physical Sciences** class.

Mentor teacher's signature………………………… Date: …………………………

Letter to the parents

July 2016

Dear parent

RE: Request to allow child to be present in a lesson that will be observed and video recorded.

I am currently conducting a study titled *Pre-service teachers' development of PCK in electromagnetism* I am investigating the role the training of Education students plays in the development of their knowledge about and skills in teaching the topic of electromagnetism to grade 11 learners.

To accomplish this goal I plan to observe, video record and interview the student teachers during their teaching practice period at schools. These observations and video recordings will take place during the normally scheduled "crit lessons" that are arranged by the students. I will adhere to the requirements and principles of ethical conduct during these activities.

I hereby request your consent to allow your child to be in present two lessons conducted by the student teacher while video recordings are being made. The faces of learners present in the class will not be captured on video camera and no data will directly be obtained from the learners.

Your decision to accept or decline this invitation will **not** have any adverse effect on your child or on the school. Should you accept this request, anonymity and confidentiality will be guaranteed at all times. Your child's name, the name of the student and that of your school will not be disclosed to anyone. The information collected during the research will be used for research purposes only. All data collected may be made available in an open repository for public and scientific use, but the identity of all persons and institutions involved will be kept anonymous.

Should you choose not to give consent your child will not be removed from the class, but will be placed in the back of the classroom out of view of the camera.

Yours faithfully

Mrs C Coetzee
Researcher

Prof. Marissa Rollnick
Supervisor
WITS University

Dr. E Gaigher
Co-supervisor
University of Pretoria

Prof Gerrit Stols
Head of Department
Science, Mathematics and Technology Education
Faculty of Education
University of Pretoria

Declaration of informed consent by parents

Research project*: Pre-service teachers' development of PCK in electromagnetism.*

I the undersigned, has read and understood your intentions, and I hereby grant consent to the researcher to observe and video record two lessons where my child will be present.

Parent's signature………………………… Date: ……………………………

Letter to the learners

July 2016

Dear learner

RE: Request to give assent to be present in a lesson of a student teacher that will be video recorded.

I am currently conducting a study in which I am investigating the role the training of Education students plays in the development of their knowledge about and skills in teaching the topic of electromagnetism to grade 11 learners.

I hereby request your assent to be present in a class where video recordings of two lessons of a student teacher will be made. The faces of learners present in the class will not be captured on video camera and no data will directly be obtained from you, the learner. I, the researcher, will have no direct interaction with you as the learners, other than being present in the class where the student is teaching and making a video recording of the student presenting the lesson. I will adhere to the requirements and principles of ethical conduct during these activities.

Should you choose not to give assent you will not be removed from the class, but will be placed in the back of the classroom out of view of the camera.

Yours faithfully

Mrs C Coetzee
Researcher

Prof. Marissa Rollnick
Supervisor
WITS University

Dr. E Gaigher
Co-supervisor
University of Pretoria

<u>Declaration of informed assent by of a grade 11 learner</u>

Research project*: Pre-service teachers' development of PCK in electromagnetism.*

I hereby grant assent to be present during the lessons taught by the student while video recordings are being made. I understand that the video recording will focus on the student and that the faces of the learners will not be captured.

Learner's signature………………………… Date: ……………………………