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Development of teachers' pedagogical content knowledge in the topic of electromagnetic induction following an intervention

Lister Munodawafa Dzikiti [1*], Estelle Gaigher [1], Coréne Coetzee [1]

[1] University of Pretoria, Pretoria, SOUTH AFRICA

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Abstract

This paper reports on a pragmatic, mixed methods study, investigating development of pedagogical content knowledge (PCK) amongst grade 11 science teachers in the topic of electromagnetic induction (EMI), following a novel PCK intervention. Four teachers from one of the provinces in South Africa attended a training workshop introducing the construct of PCK and its components, as well as the content representation tool, using familiar topics as examples, while avoiding the topic of EMI. Qualitative data show PCK development in EMI amongst the four participating teachers. Quantitatively, learners (n = 200) taught by these four teachers outperformed a control group (n = 211) in a post-test on EMI, providing evidence of their teachers' enhanced PCK. These results indicate that the intervention enabled teachers to apply knowledge about PCK acquired during the workshop to the topic of EMI. We concluded that PCK interventions, based on familiar topics, can enable teachers to transfer PCK strategies to a specific topic.

Keywords: pedagogical content knowledge, content representation, electromagnetic induction, PCK intervention, transfer of PCK strategies

INTRODUCTION

The global research community has acknowledged pedagogical content knowledge (PCK) as a leading construct required for characterizing the knowledge of the science teacher, and the role it plays in supporting the process of effective teaching and learning (Park & Suh, 2015). Therefore, PCK interventions have been evaluated by assessing teachers' PCK and student outcomes (Kirschner et al., 2015).

Shulman's (1986) basic ideas describing PCK, such as prior knowledge, learner difficulties, suitable *representations* and *conceptual teaching strategies* are utilized in the content representation (CoRe) tool developed by Loughran et al. (2004). PCK studies indicate that using CoRes in lesson planning developed teachers' PCK for specific topics (e.g., Ekiz-Kiran et al., 2021; Khoza & Ndlovu, 2025; Nilsson & Loughran, 2012).

Various science topics were utilized to investigate the success of PCK interventions. These topics include: quantitative chemistry (Hume & Berry, 2010), chemical equilibrium (Mavhunga & Rollnick, 2018), stoichiometry (Ndlovu & Malcolm, 2022), graphs of motion (Mazibe, 2017), particulate nature of matter (Buma & Sibanda, 2022), organic chemistry (Akinyemi & Mavhunga, 2021), electrostatics (Mazibe et al., 2023), geometrical optics (Erwin & Rustaman, 2017), heat and temperature (Aydeniz & Gurcay, 2018), electromagnetism (Coetzee et al., 2022), and sustainable development (Forsler et al., 2023). The interventions were all reported to enhance PCK in the relevant topics.

Literature also shows that topic specific pedagogical content knowledge (TSPCK) interventions were useful to enhance PCK in problematic science topics (e.g., Aydeniz & Gurcay, 2018; Mavhunga & Rollnick, 2013). However, TSPCK interventions also present challenges. Firstly, such interventions may also develop content knowledge of the particular topic. Such enhanced content knowledge would in turn lead to enhanced PCK (Schiering, 2023). Therefore, topic specific interventions complicates the distinction between effects of enhanced content knowledge and enhanced PCK. Secondly, TSPCK training for each topic would be time-consuming and costly as pointed out by Mavhunga et al. (2016).

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✉ munodadz@gmail.com **(*Correspondence)** ✉ estelle.gaigher@up.ac.za ✉ corene.coetzee@up.ac.za

Contribution to the literature

- This study expands the literature on PCK interventions as well as transfer of PCK strategies.
- The use of familiar topics in a single PCK intervention is an efficient way to develop teachers' knowledge about PCK.
- It enables them to transfer PCK strategies to other topics including challenging topics.

These challenges can be overcome if PCK strategies can be applied to other topics, as demonstrated amongst pre-service teachers in physics and chemistry (Mavhunga et al., 2016). Such transfer involves pedagogical transformation of new content (Deng et al., 2026, Langsford, 2020; Mavhunga et al., 2016). However, it is unclear how PCK interventions should be designed and presented to optimize benefits.

We argue that using familiar topics to develop knowledge *about* the PCK concept would enable teachers to apply PCK skills to any topic, including challenging topics. For our study, we selected the topic of electromagnetic induction (EMI) in view of reports about teachers' inadequate PCK (Liepertz & Borowski, 2019) as well as learners' challenges (Sorge et al., 2019) and misconceptions (Hekkenberg et al., 2015) in EMI. The research question was formulated as follows:

To what extent can an intervention, focused on knowledge about PCK, enhance teachers' PCK in the topic of EMI?

The question was explored qualitatively in terms of teachers' use of PCK components and quantitatively in terms of student outcomes. The results of the study may provide deeper knowledge about transferring PCK strategies to new topics. Furthermore, the results of the study may lead to more effective professional development.

LITERATURE REVIEW

PCK

Shulman (1986) described PCK as the specific type of knowledge which embraces the aspects of content most crucial to its teaching. Specifically, Shulman (1987) pointed out that PCK involves the teacher's translation of content knowledge into forms adapted to an individual learner's learning difficulties and prior knowledge. Abell (2008) supported Shulman's (1987) advocacy for a PCK construct, which included the total comprehension, full organization, and proper presentation of topic-specific problems to cater for the diverse interests of learners of various abilities. According to Berry et al. (2008), PCK enables teachers to present subject content conceptually. Furthermore, Miheso and Mavhunga (2020) emphasized that PCK assists physical sciences teachers to confront learners' misconceptions, thereby supporting the learning process. However, it is difficult to capture PCK due to its personal and tacit nature, based on teachers' unique knowledge of practice (Kind, 2009). Nevertheless, the constructs of TSPCK and PCK components enable researchers to give a detailed description of PCK.

TSPCK was introduced by Veal and MaKinster (1999), as the most detailed level of PCK in their taxonomy of PCK. Mavhunga and Rollnick (2013) identified five components to characterize TSPCK:

(1) knowledge of the *curricular saliency*,

(2) *what is difficult to teach*,

(3) *learner prior knowledge*,

(4) *representations* including analogies, and

(5) *conceptual teaching strategies*.

Two of these components, *what is difficult to teach* and *learner prior knowledge,* were combined into *learner knowledge* in the grand rubric (Chan et al., 2019), which also introduces 2 new components, *pedagogical reasoning* and *integration between components*.

Loughran et al. (2004) developed a useful instrument, the CoRe, which guides teachers to reveal their knowledge and reasoning about the teaching of any particular topic. Firstly, the teacher is requested to provide a few big ideas, i.e., concepts fundamental to the understanding of a specific topic. Next, the teacher is prompted to present their thoughts about aspects such as learners' prior knowledge, possible misconceptions, and *representations* related to understanding these big ideas. According to Loughran et al. (2004, 2012), it is worthwhile for a teacher to complete a CoRe before lesson execution as it may assist in lesson planning. Completing CoRes also serves a developmental purpose, by enabling teachers to "make the tacit explicit in ways that developed their understanding" (Berry & Loughran, 2010). Park et al. (2025) observed divergences which arise from the conceptualization, operationalization, and PCK measurement. Several studies attest to such development by using CoRes. For example, Buma and Sibanda (2022), used the CoRe-tool to investigate the development of the PCK of grade 8 natural sciences teachers by requesting participants to complete CoRes before and after a training intervention about the particulate nature of matter. Khoza and Ndlovu (2025) reported PCK development amongst pre-service biology teachers who constructed CoRes during lesson planning. Forsler et al. (2023) used the CoRe as instrument to together with video-based reflection to capture and develop teachers' PCK in sustainable development. Mavhunga et al. (2016) reported transfer

of PCK strategies amongst student teachers by using CoRes in lesson planning.

The value of PCK ultimately lies in its influences on student outcomes, as suggested by experts in the study field of PCK: "… 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 et al., 2015, p. 234). Accordingly, the effect of PCK on student outcomes has attracted some research interest. Several studies found a positive relationship (e.g., Alonzo et al., 2012; Keller et al., 2017; Mazibe, 2020) while Gess-Newsome et al. (2019) reported that there were no links between PCK and student learning. Therefore, the value of interventions to enhance teachers' PCK should also be evaluated in terms of their effect on learner outcomes.

Electromagnetism

Electromagnetism, which includes EMI, has proved to be an unpopular, abstract, difficult topic to teach and learn (Dori & Belcher, 2005). This, according to Jelicic et al. (2017), leads to teachers resorting to the use of undocumented and unscientific models when explaining EMI to learners. Research in physics education has repeatedly shown that students' level of conceptualization of electromagnetism is idiosyncratic, involving common and non-scientific terminology (Koudelkova & Dvorak, 2014). Students who are able to deal with higher-order algorithmic problems often lack conceptual understanding of the phenomena (Jelicic et al., 2017). Learning challenges are not surprising as EMI concepts are regarded as difficult since they consist of abstract relations (Chabay & Sherwood, 2006). Furthermore, studies on EMI assessments have indicated that difficulties in the topic are experienced globally (Maloney et al., 2001; Sağlam & Millar, 2006).

In South Africa, it was reported that learners' alternative conceptions in electromagnetism are retained even after being taught and that some science teachers have alternative understandings (Hekkenberg et al., 2015). Kriek and Grayson (2009) noted that misconceptions in EMI are not only prevalent amongst learners, but also amongst the teachers. Furthermore, tightly scheduled school curricula allow insufficient time to internalize abstract concepts such as magnetic flux (MF) and induced electromotive force (Coetzee et al., 2022). As a case in point, the diagnostic report of South Africa's physical sciences national year-end examinations of 2014 indicates that one of the contributing factors to poor performance is misconceptions held by learners related to how EMI enables the operation of a generator (Department of Basic Education, 2015). Furthermore, a recent PCK study on the teaching of the topic of EMI (Coetzee et al., 2022) revealed that novice teachers experienced challenges in the teaching of the topic, specifically Faraday's law (FL). Given the challenges associated with the topic of EMI as described above, this topic was selected for the current study to investigate the effects of a PCK intervention on teachers' PCK in EMI.

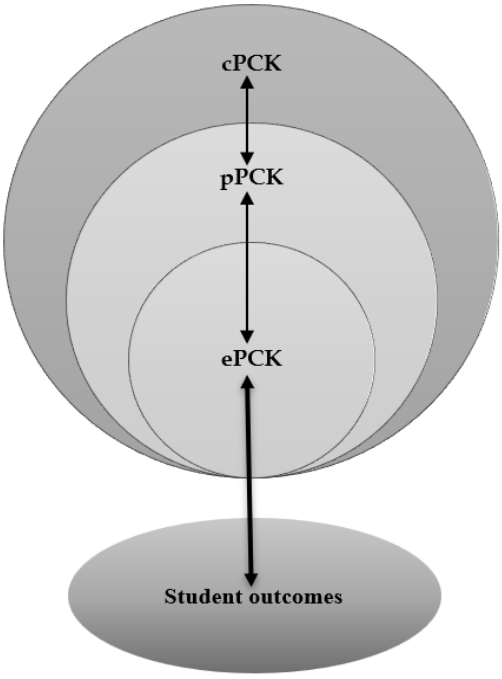


Figure 1. The conceptual framework adapted from the RCM (Carlson et al., 2019)

Conceptual Framework

The conceptual framework, shown in **Figure 1**, is based on the refined consensus model (RCM) (Carlson et al., 2019). The frame represents a flow of knowledge from the professional community to teachers and ultimately to learners.

The collective PCK (cPCK) refers to PCK held by the profession. A teacher usually is exposed to cPCK during pre-and in-service training and through interactions with peers. Personal PCK (pPCK) is unique to every individual teacher, informed and developed through exposure to cPCK and interaction with the topic, the learners and the context during teaching. During the planning and teaching of a lesson, teachers draw from their reservoirs of pPCK, presenting enacted PCK (ePCK). Ultimately, the ePCK of the teacher impacts learner outcomes. The arrows in **Figure 1** indicate how the effect of an intervention can be viewed as a transfer of cPCK to pPCK, which develops ePCK, and in turn impacts learner performance.

The components of TSPCK exist within each of the three PCK realms represented in conceptual framework. Mavhunga and van der Merwe (2020) pointed out that the RCM applies to any topic; in the current study it applies to the topic of EMI. The adoption of the conceptual framework outlined above assisted us to explore the effect of the intervention on the teachers' PCK in EMI, by investigating pPCK, ePCK, and learner performance.

METHODOLOGY

Design

The research methodology was guided by the research question, exploring the effects of a PCK intervention on teachers' PCK in the topic of EMI. From a pragmatic stance, we adopted a mixed methods approach, enabling us to track PCK development qualitatively for four teachers, and quantitatively, comparing the performance of their learners to that of a control group. Learners' performance in tests was regarded as an indicator of their teachers' PCK in accordance with the conceptual frame. Teachers of the control group learners did not participate in the qualitative part of the study, as exposure to PCK concepts could result in contamination, influencing their learners' performance in the post-test.

The study was designed to cause no disruption of the prescribed school routine, departmental teaching schedule, or compulsory testing as we synchronized data collection with the schedule of teaching and testing as prescribed by the department. The EMI topic was taught in line with the national curriculum and annual teaching plan, which required four lessons per class, each lasting for an hour. Furthermore, learners' test results were also utilized by the schools for formal, prescribed testing to ensure productive use of time. Learners remained in their normal classes into which they were assigned by their schools at the beginning of the academic year and with the same teachers.

Sample

The study was conducted in eight government schools in a rural educational district in the Mpumalanga province in South Africa. The schools were not partnering with the university in any way and were conveniently selected for their location in the first author's home province.

The teachers were all qualified to teach physical science and all had BEd degrees. The qualitative part of the study was conducted amongst the grade 11 science teachers of the 4 schools forming the experimental group. The teachers of the four schools allocated to the control group did not participate in the intervention or data collection activities. The quantitative part of the study involved all grade 11 learners studying science at all these schools.

The participating schools were divided into two groups by matching the learner performance in a baseline test. This test covered the topic of grade 11 Mechanics, which was taught and completed at the start of the school year, prior to the intervention. This allocation enabled us to assume that the two learner groups were equivalent regarding the competence in a gr. 11 topic as taught by their teachers. This assumption is justified by statistical analysis, as discussed in the results section. The classes were not all exactly of the same size, resulting in the treatment group consisting of 200 learners while the control group had 211 learners.

Intervention

The four teacher participants attended a 3-hour workshop presented by the first author. He explained the PCK construct, discussed components and introduced the CoRe template as an instrument that guides teachers to express their PCK on any topic. The presenter deliberately refrained from using examples from EMI while discussing the CoRe-tool. Instead, examples from other familiar topics, such as equations of motion and circuits, were used. Next, the teachers worked in pairs to complete the CoRe-tool applied to a specific familiar grade 11 topic, namely Newton's laws of motion, which they taught earlier in the year according to the grade 11 syllabus. This exercise assisted teachers in familiarizing themselves with the use of the CoRe-tool. After completing the CoRe-tool further questions from the teachers were discussed to ensure that they understood how to use the tool on their own. Teachers were then requested to use the CoRe-tool as part of lesson planning for teaching EMI later during the school term.

Data Collection

Qualitative data

Qualitative data were collected from the four participating teachers to track the development of their PCK in the topic of EMI. Two datasets, based on CoRes, were collected for each teacher. Prior to the intervention, teachers completed a questionnaire based on the CoRe prompts, applied to the topic of EMI. We refer to this questionnaire as the pre-CoRe. The question format was preferred at this stage of the study as the participants were not yet familiar with the template format of the standard CoRe-tool. During the lesson preparation to teach the EMI topic, the teachers completed the CoRe template, referred to as post-CoRes in this study. These two CoRes we regarded as indicators of the teachers' pPCK, before and after the intervention. For the pre-CoRe as well as the post-CoRe, the researchers supplied two big ideas, namely MF and FL.

During the teaching of EMI, video-recorded lesson observations were carried out when the teachers taught the topic of EMI, providing a third dataset, regarded as an indicator of the teachers' ePCK. Four full lessons for each teacher were observed and video recorded, each lesson lasting an hour.

Quantitative data

Quantitative data were obtained for the two groups of learners, using the baseline test and a post-test These tests were aligned to the national curriculum for grade

Table 1. Extract from the PCK scoring rubric for the component *curricular saliency*

Component prompts	Limited (1)	Adequate (2)	Development (3)	Exemplary (4)
A. Knowledge of *curricular saliency*				
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 sequential development	- Reasons provided exclude considerations such as scaffolding/ sequential development. - Reasons include reference to the selected key and sub-ordinate ideas rather than topics that follow	- Reasons provided include evidence of understanding of conceptual scaffolding/ sequential development	- Reasons provided include conceptual scaffolding/ sequential development of understanding of specified subsequent topics in the subject. - Understanding of the importance of the key idea in relation to other ideas in the subject matter

11 with questions of a similar level to those found in the national year-end examination papers of the Department of Basic Education (2015). Testing was aligned to the departmental schedule, to enable teachers to use the results for their official assessment. The baseline test was written on the topic of Mechanics, after the topic was taught at all the schools, prior to the intervention as explained earlier. The post-test, on EMI, was written after the topic of EMI had been taught at all schools. Pragmatically, the baseline test was used as a proxy for a pre-test, as the school schedule did not allow time for a pre-test on EMI prior to teaching on EMI. The national senior certificate examination rules and regulations were strictly adhered to in both the baseline and post-test.

Instruments and Data Analysis

Qualitative data analysis

The PCK of the participating teachers was scored for the pre-CoRe, post-CoRe and ePCK using an adaption of the TSPCK rubric of Mavhunga and Rollnick (2013), adapted by Coetzee et al. (2022) for EMI. We merged the components *learner prior knowledge* and *what is difficult to teach* into a single component *learner understanding*, in line with the grand rubric (Chan et al., 2019) and similar to Vollebregt et al. (2021). Our rubric therefore had three PCK components namely *curricular saliency*, *learner understanding*, and *representations* including conceptual teaching strategies. The descriptors for the four levels were based on the big ideas of MF and FL for grade 11 EMI. An extract from the rubric is shown in **Table 1**, specifically for the component *curricular saliency*.

Data analysis entailed comparing CoRes and transcripts of recorded lessons to the criteria specified in the rubric for each PCK component. Scoring was conducted independently by the authors, allocating a score on a scale of 1 to 4 to represent competence in each PCK component, for the pre-CoRe, the post CoRe and enactment of PCK. Finally, the authors compared scores and discussed differences to reach consensus.

The scores from each teacher's pre-CoRe, post-CoRe and ePCK were compared to track PCK development, separately for the components. For a quantitative comparison, the scores were represented on a numerical scale of 1 to 4, where 1 = limited, 2 = adequate, 3 = developing and 4 = exemplary. The numerical scores were then added and averaged for each of the pre-CoRe, post-CoRe and ePCK scores per teacher.

Quantitative data analysis

The baseline test and post-test were scored by the first author. The performance of the two groups in the baseline test was compared statistically to check if there were significant differences between the treatment and the control groups prior to the intervention. After the intervention, the performance of the groups was again compared in post-test to establish if there were significant differences between the treatment and the control groups. For the baseline comparison as well as for the post-test comparison, the null hypothesis was formulated as follows:

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

Validity and Trustworthiness

The trustworthiness of qualitative results was enhanced by crystallization, using multiple data collection methods. Furthermore, we used an existing rubric, which was developed by Coetzee (2018). All three authors participated in scoring and discussed differences to reach consensus.

For quantitative data, both the baseline and post-tests were set by the first author (Dzikiti, 2023) being guided by the national curriculum and grade 11 physical sciences examination guidelines. The tests were in multiple choice format, allowing for objective scoring and checked by the subject matter experts well as departmental subject advisors for expert validation.

Ethics

Ethical approval for the study was obtained from the Faculty of Education Research Ethics Committee (ethics certificate number: EDU035/21). Permission to conduct the research was granted by the Mpumalanga

Table 2. Summary of experimental group teachers' numerical PCK scores on a 4-point scale

Teacher	PCK component	Scores								
		Pre-CoRe			Post-CoRe			ePCK		
		MF (4)	FL (4)	Average (4)	MF (4)	FL (4)	Average (4)	MF (4)	FL (4)	Average (4)
TE1	*Curricular saliency*	1	2	1.5	3	3	3.0	2	2	2.0
TE2		2	2	2.0	3	4	3.5	3	3	3.0
TE3		3	3	3.0	4	4	4.0	3	3	3.0
TE4		2	2	2.0	3	2	2.5	3	1	2.0
					2.2		3.3			2.6
TE1	*Learner understanding*	1	1	1.0	3	2	2.5	2	2	2.0
TE2		2	2	2.0	3	3	3.0	3	3	3.0
TE3		2	3	2.5	3	3	3.0	3	3	3.0
TE4		2	2	2.0	3	2	2.5	2	1	1.5
						1.9		2.8		2.4
TE1	*Conceptual teaching strategies*	1	3	2.0	3	3	3.0	3	2	2.5
TE2		3	3	3.0	4	4	4.0	3	3	3.0
TE3		3	3	3.0	4	3	3.5	3	3	3.0
TE4		2	2	2.0	3	2	2.5	2	1	1.5
						2.4		3.3		2.6
TE1	*Representations*	2	2	2.0	3	3	3.0	2	3	2.5
TE2		3	3	3.0	3	4	3.5	2	3	2.5
TE3		2	3	2.5	4	4	4.0	3	3	3.0
TE4		2	1	1.5	2	2	2.5	2	1	2.0
						2.3		3.3		2.3

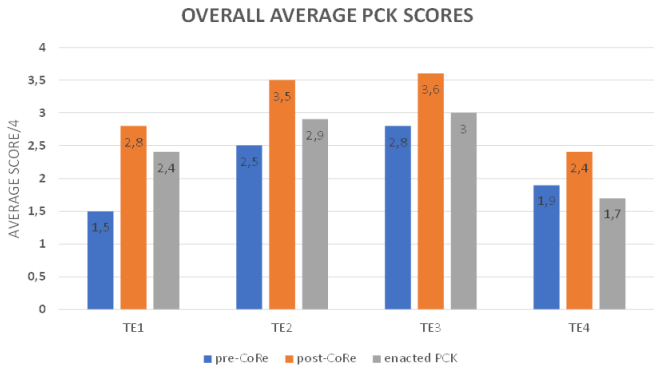


Figure 2. Average PCK scores for all treatment group teachers (Dzikiti, 2023)

Department of Education and the principals of the participating secondary schools. All procedures involving human participants were conducted in accordance with institutional ethical standards. Informed consent was obtained from all participating teachers, and confidentiality and anonymity were assured throughout the study.

RESULTS

Qualitative Findings

Table 2 presents the scores for PCK components allocated to the participating teachers for the pre-CoRe, post-Core and enactment of PCK in the topic EMI, separately for the big ideas MF and FL.

The PCK development of the participating teachers in EMI is illustrated in **Figure 2**, showing the average scores for the pre-CoRe, post-CoRe and ePCK for each teacher

Figure 2 shows that the average PCK increased from pre-CoRe to post-CoRe for all participants suggesting an improvement in PCK that we ascribe to the intervention. However, the ePCK scores were lower than for the pPCK measured in the post-Core for all participants. Nevertheless, the ePCK scores also showed improvement compared to the pre-CoRe scores for three of the four teachers. These results suggest that the intervention did enhance the teachers' PCK in EMI but that this enhanced PCK was ineffectively enacted during teaching. One of the teachers (TE4) was an exception to this trend, scoring even lower in enactment than in the pre-CoRe. We ascribe the poor enactment to the inadequate content knowledge this teacher demonstrated while teaching EMI, for example, in the inability to answer learners' questions.

To illustrate how the PCK changed during the course of the study, the case of TE2 is presented below, focusing on the component of *curricular saliency*. **Figure 3** and **Figure 4**, respectively show his answers for the big ideas MF and FL in the pre-CoRe, while his answers for the post-CoRe are shown in **Figure 5**.

In the pre-Core, for the big idea MF, TE2 indicated that he intended his learners to define MF and perform calculations. For the big idea of FL, he wanted his learners to understand FL and Lenz's law. His response to question 3.5 is inappropriate, as this content needs to be taught as part of FL. He thus scored 2 for both MF and FL for the pre-CoRe. For the post-CoRe, the teacher indicated that learners should understand the right-hand rule (RHR), flux and change in flux as pre-concepts for FL.

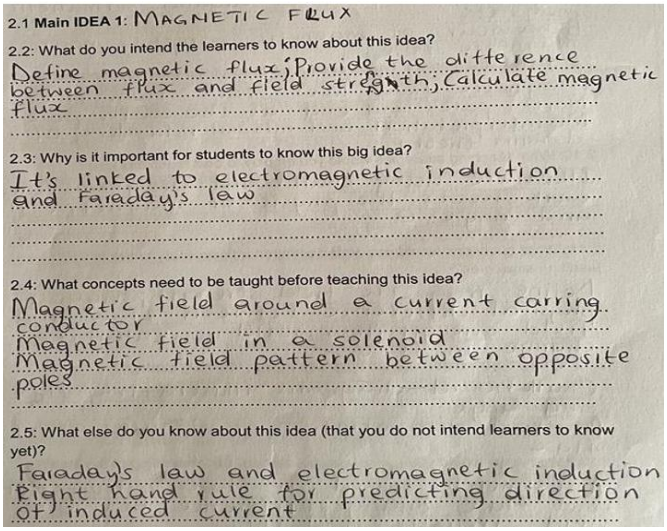


Figure 3. TE2's pre-CoRe responses to *curricular saliency* based on the big idea of MF (Dzikiti, 2023)

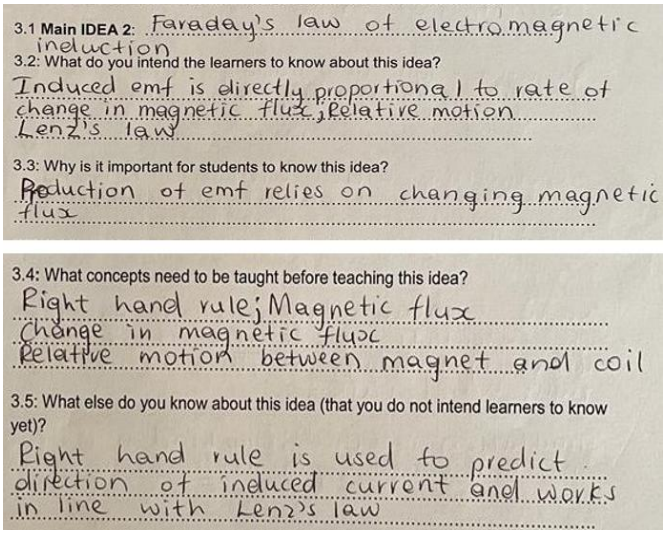


Figure 4. TE2's pre-CoRe responses to *curricular saliency* based on the big idea of FL (Dzikiti, 2023)

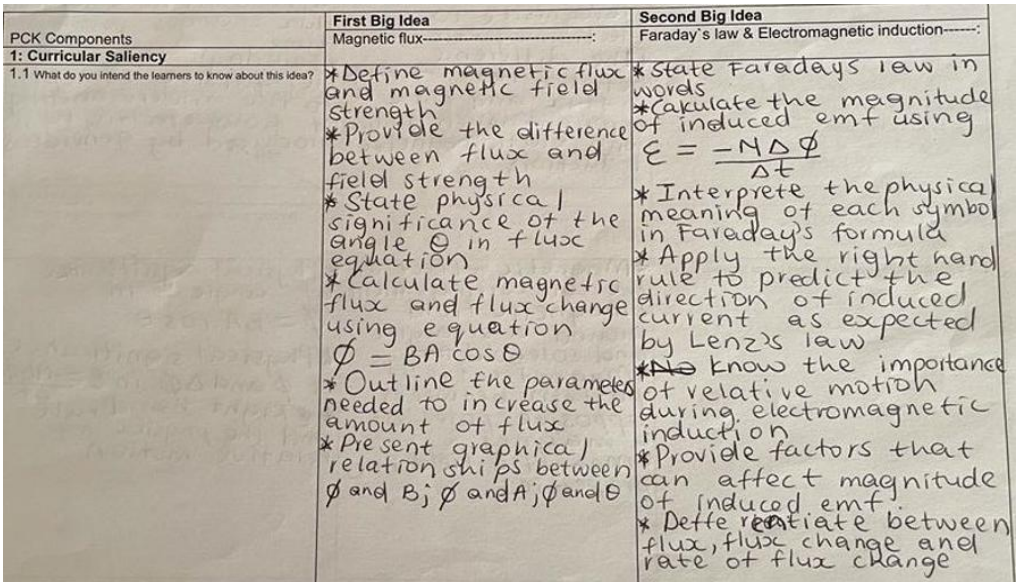


Figure 5. *Curricular saliency* for MF (left) and FL (right) from the post-Co-Re of TE2 (Dzikiti, 2023)

Evidently, TE2 displayed enhanced PCK (as shown in **Figure 5**) for both MF and FL with more insight and detail than in the pre-CoRe, (demonstrated by **Figure 3** and **Figure 4**) reflected by enhanced scores of 3 and 4, respectively. For ePCK His lesson presentation reflected most aspects of *curricular saliency* for MF as suggested in the post-Core, reflected in an unchanged score of 3. For FL, his enactment of *curricular saliency* did not include an explanation of Lenz's law. Instead, he simply told his learners:

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

This explanation is valuable to alert learners to the fact that the RHR should be applied to the induced field. However, he did not explain the essence of the law: The direction of the induced field and current is such that it opposes the cause of induction. This shortcoming illustrates why his *curricular saliency* for FL was scored 3 for ePCK, dropping from 4 in the post-CoRe.

Despite recognition of the importance of *learner understanding,* teachers did not adequately address learners' challenges with understanding new content during lesson presentation, particularly the angle in the formula for FL and conceptual understanding of Lenz' law. Regarding *conceptual teaching strategies*, TE3 attempted to demonstrate the phenomenon of EMI to his learners. However, the demonstration was not successful, suggesting that he did not test the apparatus beforehand, resulting in a score of 3, dropping from 4 as obtained in the post-CoRe.

Table 3. Comparison of control group baseline test with experimental group baseline test (n = 411)

Test	Group	N	Median	Mann-Whitney U test	p
Baseline test	Control group	211	45	20,461.5	0.594
	Experimental group	200	47		

Table 4. Comparison of control group post-test with experimental group post-test (n = 411)

Variable	Group	N	MR	Mann-Whitney U test	p	r
Post-test	Control group	211	185.05	18,789.0	0.043	0.094
	Experimental group	200	217.56			

Generally, post-CoRe scores were higher than ePCK scores after class observations, as seen in **Figure 2**. This gives the general impression that the sampled teachers had some challenges of effectively enacting their PCK. Although individual teachers might have faced challenges during PCK enactment, footprints of the effectiveness of the intervention were evident for some specific PCK components. For example, all the sampled teachers introduced their lessons by reflecting on the magnetic field around a coil carrying current, which is important to understand induction in a coil. In other words, there was some recognition of *learner understanding*, consistent with their post-CoRes.

Quantitative Findings

For the baseline test comparison, a Mann-Whitney U test was implemented to compare the two groups. The test was conducted at a 5% level of significance to determine the difference between the baseline test scores for the two groups. The results are shown in **Table 3**.

There was no significant difference between the control group baseline test (median = 45) and the experimental group baseline test (median = 47) ($U = 20{,}461.5$, $p = 0.594 > 0.05$). Therefore, the null hypothesis was accepted, meaning the performance in the baseline test was not significantly different between the control group and the experimental group. This was conclusive evidence indicating that before the intervention, the control group and the experimental group performed at the same level in a completed grade 11 topic. For the post-test comparison, the Mann-Whitney U test was again conducted at a 5% level of significance. The test results are shown in **Table 4**.

The results reveal a significant difference in performance between the control group post-test (mean rank [MR] = 185.05) and the experimental group post-test (MR = 217.56) ($U = 18{,}789.0$, $p = 0.043 < 0.05$ and $r = 0.094$). The null hypothesis was thus rejected, indicating that the performance of the experimental group was significantly better though with a small effect size (r) than that of the control group. We therefore infer that the teachers of the experimental group displayed better PCK during teaching EMI as compared to the teachers of the control group.

DISCUSSION

The study revealed quantitative and qualitative evidence indicating that the PCK in the topic of EMI was enhanced by the intervention. Qualitatively, the participating teachers' PCK in EMI as revealed in their post-CoRes and lesson enactment, was predominantly rated at a higher level as compared to the pre-CoRes. This increase provides evidence that the intervention was instrumental in PCK development amongst these four teachers. Quantitatively, the statistical analysis showed that learners from the two groups performed similarly in the baseline test on a grade 11 topic (mechanics) that was completed prior to the intervention. However, the treatment group outperformed the control group in the post-test on EMI, while taught by the same teachers as for the baseline test. We thus conclude that the learners in the experimental group received instruction rooted in higher PCK when compared to the control group in the topic of EMI. We attribute this difference to the PCK intervention.

Based on qualitative as well as quantitative evidence discussed above, we therefore propose that teachers acquire knowledge about the nature of PCK in terms of components and strategies during the intervention, enabling them to apply this knowledge to the topic of EMI. We suggest that the use of familiar topics during the intervention developed teachers' PCK competence, which was transferred to the challenging topic of EMI. Similar to other studies (e.g., Mavhunga et al., 2016), we argue that this transfer was mediated by the process of completing CoRes as part of lesson preparation for teaching EMI. Furthermore, the results support literature (e.g., Ekiz-Kiran et al., 2021; Khoza & Ndlovu, 2025) showing that using CoRes in lesson planning develops PCK. While our focus was on the topic of EMI, the results may also apply to other topics. We recommend that further research be undertaken to investigate whether using of familiar topics in interventions mediates transfer to other challenging topics.

While we found that learners in the experimental group outperformed the control group, our study was not designed to investigate the mechanism of how teachers' PCK enabled knowledge development amongst their learners.

It is recommended that such issues be investigated in further PCK studies, like that of Mazibe (2020), showing footprints of teachers' lesson presentations in learners' answers to extended response test questions.

Though the PCK for EMI was enhanced for all four participating teachers, these teachers all had some challenges to effectively enact their PCK, similar to reports in the literature (e.g., Coetzee et al., 2022; Mazibe, 2024). This divide between theory and practice (Mavhunga & van der Merwe, 2020) may be caused by difficulties to explain concepts (Kind, 2009), poor understanding or misconceptions amongst the participating teachers (Mavhunga, 2018) or poor subject matter knowledge (Krepf et al., 2017). Specifically, the teachers in our study revealed gaps in subject matter knowledge, e.g., to conceptually explain the negative sign in FL, and to apply the RHR together with Lenz's law. The challenge regarding Lenz's law in particular supports claims that PCK also exist at a concept level (Mazibe, 2020).

The component *knowledge of learner understanding* was the poorest ePCK component. For example, in the current study, TE3 was the only participant who showed awareness of the learners' difficulty visualizing the angle in the equation when calculating flux, while TE2 was the only one alerting the learners to apply the RHR to the *induced* magnetic field (rather than the original) when applying Lenz' law. The poor awareness of the importance of *learner understanding* concurs with Mthethwa-Kunene et al. (2015), and Mapulanga et al. (2022), who observed that teachers' pedagogical decisions were ineffective due to their inadequate understanding of learners' prior knowledge.

While the study demonstrates the value of using familiar topics in a PCK intervention, it also exposes various content-related challenges based on the topic of EMI to grade 11 physics teachers in South Africa. The content-related challenge at the forefront was the interrelatedness between FL and Lenz's law. This was demonstrated in difficulties when explaining the negative sign when dealing with FL, and in determining the direction of the induced current.

The sample size does not justify the generalizability of research findings. Furthermore, this study did not involve elements of longitudinal research to enable effective follow-up on long term effects of the intervention. Additionally, the Mann-Whitney U test assumes independent observations. Hence, we acknowledge the risk of inflated type I error that is likely to arise due to clustered student performance at classroom/teacher level. The Hawthorne effect may have contributed to the results in the sense that participating in the study may have contributed to the teachers' efforts while teaching the topic of Electromagnetism.

The outcome of this study provides evidence suggesting that a PCK intervention introducing knowledge *about* PCK using familiar topics can enable teachers to transfer PCK strategies to any specific topic, thereby saving time and money that would be needed for several TSPCK interventions. We propose that the transfer was mediated by completing CoRes during lesson preparation. Further studies are recommended to investigate the mechanism for transfer of PCK strategies to new topics.

CONCLUSION

While it is generally accepted that PCK is an important aspect of a teacher's professional knowledge base and that PCK is topic-specific, it is not feasible to expose pre-service teachers during initial training or in-service teachers during workshops to TSPCK of all possible curriculum topics. In the current study, we introduced an intervention focused on the *nature* of PCK, emphasizing its description in terms of components, applied to more than one familiar topic to keep the focus on PCK rather than on the intricacies of a specific topic. We found that this intervention supported teachers to transfer PCK strategies to a challenging topic, EMI. We believe that such an intervention allows in depth knowledge about the PCK construct that would benefit development of PCK in any topic. The success of focusing on the *nature* of PCK in an intervention is a promising a new contribution to the PCK research field. Importantly, the study highlights the value of PCK as a construct independent of specific content knowledge. The results of the study may lead to more effective professional development in PCK, replacing the need for PCK interventions in several topics.

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Ethical statement: This study was approved by the Faculty of Education Research Ethics Committee with approval number EDU035/21. Permission to conduct the research was granted by the Mpumalanga Department of Education and the principals of the participating secondary schools. All procedures involving human participants were conducted in accordance with institutional ethical standards. Informed consent was obtained from all participating teachers, and confidentiality and anonymity were assured throughout the study.

AI statement: The authors did not use AI tools such as generative AI, ChatGPT to conduct research or to write this manuscript. No part of this manuscript has AI elements. The authors only used the traditional computing software such Microsoft word for writing the manuscript and Microsoft excel for quantitative data analysis.

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