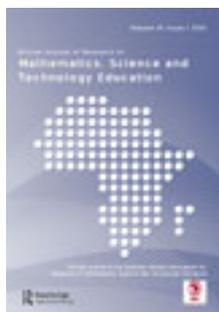


This article was downloaded by: [The Library, University of Witwatersrand]  
On: 12 September 2013, At: 01:13  
Publisher: Routledge  
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## African Journal of Research in Mathematics, Science and Technology Education

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/rmse20>

### Improving PCK of Chemical Equilibrium in Pre-service Teachers

Elizabeth Mavhunga<sup>a</sup> & Marissa Rollnick<sup>a</sup>

<sup>a</sup> Marang Centre for Mathematics and Science Education, University of the Witwatersrand, Johannesburg, South Africa

To cite this article: Elizabeth Mavhunga & Marissa Rollnick (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

To link to this article: <http://dx.doi.org/10.1080/10288457.2013.828406>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>



# Improving PCK of Chemical Equilibrium in Pre-service Teachers

Elizabeth Mavhunga\* and Marissa Rollnick

*Marang Centre for Mathematics and Science Education, University of the Witwatersrand, Johannesburg, South Africa*

\*Corresponding author, email: [Elizabeth.Mavhunga@wits.ac.za](mailto:Elizabeth.Mavhunga@wits.ac.za)

It is commonly accepted that Pedagogical Content Knowledge (PCK) has a topic-specific nature. However, its implementation in teacher education programmes has remained generic and tacit. This paper reports on an attempt to improve the quality of PCK in chemistry pre service teachers in a specified topic—chemical equilibrium. By locating PCK at a topic level, a refined theoretical description of the construct sensitive to the specificity of the topic is suggested and its validity argued. The refined description is grounded on the notion of transformation of topic-specific concepts to PCK, and the identification of components that enable such a transformation. The components were identified as Learners' Prior Knowledge, Curricular Saliency, What makes a topic easy or difficult to understand, Representations including analogies and Conceptual Teaching Strategies. The extent to which the explicit teaching of these five components influences the improvement of the quality of PCK within Chemical Equilibrium was determined in an intervention with 16 physical science pre-service teachers. The impact of the intervention was determined through mixed methods. The intervention resulted in a significant (99% confidence) overall improvement of the quality of PCK within chemical equilibrium. The findings signal a reciprocal relationship between PCK and the pedagogical transformation of concepts, where the latter was previously reported to result from PCK. Recommendations with regard to constructing PCK at a topic level in teacher education programmes are suggested with particular reference to the South African context.

**Keywords:** pedagogical content knowledge; topic-specific PCK; chemical equilibrium and transformation of subject matter knowledge

---

## Introduction

Pedagogical Content Knowledge (PCK) as a theoretical construct has become a popular hallmark for the teaching profession in many teaching disciplines including science (e.g. Jüttner & Neuhaus, 2012). While its exact nature is still to be agreed, science education researchers agree on its value for implementation in teacher education programmes (Abell, 2007; Kind, 2009). This consensus has influenced the surge in empirical studies capturing and measuring the construct, and has therefore fuelled the need for a clearly articulated model of what is to be measured. There is agreement in the literature about the topic-specific nature of PCK as a theoretical construct (e.g. Loughran, Berry, & Mulhall, 2004). This is the foundation on which the discussion in this paper is laid. We argue that the topic-specific nature of PCK suggests the need for a PCK construct that is defined more sharply to reflect the specificity of the topic rather than reference to a subject or discipline. Thus PCK in chemical equilibrium is different from PCK in physical science as suggested by Veal and Makinster (1999). In this paper, we seek to make explicit the development of PCK within a specific topic, in a teacher preparation programme. In the discussion below we first provide a rationale for implementing the idea of

PCK in teacher preparation programmes in general, highlighting the practical value of implementing topic-specific PCK in the South African context. We then argue for use of this type of PCK as a construct. Finally, we describe a case of chemistry pre-service teachers who were exposed to an intervention targeting explicit transformation of chemical equilibrium concepts with the aim of measuring its effectiveness in improving the quality of PCK in the topic.

### **PCK and Teacher Education Programmes**

The value of PCK in teacher preparation programmes is said to lie in its usefulness in understanding teachers' knowledge (Abell, 2007). In 1986, Lee Shulman drew attention to the inadequacies of regarding the teachers' knowledge base as comprised only of subject matter knowledge (SMK)<sup>1</sup> and pedagogical knowledge (PK). He argued for the interrelatedness of the two categories pointing out that for an expert teacher many of the PK strategies are content specific (Shulman, 1986). An outstanding teacher is not just a teacher, but rather an 'English teacher' or a 'chemistry teacher' (Geddis, 1993, p. 675). The implication for teacher preparation programmes is, therefore, that pre-service teachers need not only to learn how to teach but 'how to teach electricity' or 'how to teach stoichiometry'. Emphasis is to be placed on the quality of teaching a specific topic. In making explicit reference to a topic and a discipline, Geddis (1993) alludes to levels of capability in teaching. This idea was later used by Veal and Makinster (1999) who forwarded the notion of PCK taxonomies. They refer to PCK in a discipline and PCK within a topic, the latter being considered as '*the most specific and novel level*' (Veal & Makinster, 1999, p. 10). While there is general agreement about the topic-specific nature of PCK in the literature, theoretical frameworks that expand and articulate how this nature may look like are limited. As a result, the implementation of PCK in teacher education programmes remains tacit and generic. Commonly, studies measure and portray the natural development of PCK following a generic introduction to PCK and an exposure to classroom practice with emphasis on the value of reflection (Nilsson, 2008; Nilsson & Loughran, 2012). We argue below that the realisation of the topic-specific nature of PCK lies in the capacity to transform concepts within the topic by packaging them for teaching. This capacity may be developed by focusing on selective knowledge components that are oriented to SMK and reported to enable such transformation. For South Africa, in the context of the prevalence of poorly prepared science teachers (SAIRR, 2011), the idea of PCK, whose nature and novelty lies in the quality of teaching a topic by topic, provides the possibility of mastering a few in the short term. The idea also holds potential for achieving policy goals that require a teacher to be a specialist in a specific subject and educational level (Department of Education, 2000).

In this paper, we seek to explore strategies to explicitly enhance the quality of PCK in pre-service teachers. We have chosen chemical equilibrium as a topic based on research studies suggesting its foundational value in understanding other chemistry topics, such as oxidation-reduction (Bergquist & Heikkinen, 1990). Furthermore, the topic is perceived to be difficult and abstract (Tyson, Treagust, & Bucat, 1999) requiring content and terminology specific explanations. For example, the meaning of the phrase 'equilibrium' is different to the daily use of the term. Further difficulties are reported for understanding of the constant nature of the equilibrium constant (Van Driel & Graber, 2002) and the unequal concentrations of reagents at equilibrium. While this discussion on difficulties with chemical equilibrium is not exhaustive, it foregrounds the importance of knowing what makes the topic difficult. In a way, this discussion has begun the process of reasoning about teaching. It has brought to the fore considerations about the hard core SMK that must be present for effective teaching. These considerations have transformative effects on the concepts of the topic, a discussion expanded in the next section.

### **PCK within a Specific Topic—Topic-Specific PCK**

As the focus in this paper is on PCK within a topic, it is important to define the construct and provide a theoretical framework for its discussion. We start from Shulman's (1987) statement that: 'comprehended ideas must be transformed in some manner if they are to be taught' (Shulman, 1987, p. 16).

He described PCK as 'the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful' (p. 15). This statement has been the foundation of many research studies in PCK leading to the generally accepted finding of its topic-specific nature. We acknowledge the above, but further point to the interface of topic specificity of PCK and transformation of the concepts in that topic. Geddis (1993) pointed out that teachers need to develop the awareness that teaching requires the transformation of their SMK in general. Also, once this awareness is in place, the articulation of the kinds of knowledge needed to achieve such transformation becomes important. According to the author, knowledge of a 'multitude of particular things' about SMK that are relevant to its teachability is required (Geddis, 1993, p. 676). The 'particular things' are identified as (i) Students' Prior Knowledge including misconceptions, (ii) Curricular Saliency, (iii) What makes a topic easy or difficult to understand, (iv) Representations including analogies and (v) Conceptual Teaching Strategies (Geddis, 1993; Geddis & Wood, 1997). We have called these components *content-specific components* because of their orientation to SMK, requiring specific considerations to be made about SMK. When a particular element of SMK (K, in Figure 1) is thought about and reasoned through these content-specific components, understanding for teaching is generated that is specific to that topic (K'). That is, the initial element of SMK is transformed to a version that is suitable for use in teaching learners. In Mathematics, similar content-specific components are found in the description of 'Specialized Content Knowledge' (SCK). SCK is a construct that provides the knowledge required for SMK transformation needed only in teaching settings (Ball, Thames, & Phelps, 2008).

In this study we consider the quality of teaching resulting from such considerations influenced by both the knowledge of the content-specific components as well as their interaction among each other. Similar to Shulman, however specific to a topic level, we have termed the capacity to transform SMK of a topic through such considerations as PCK located within that topic (Topic-Specific PCK). This transformation is displayed on the left-hand side of Figure 1 as explained above. The right-hand side of the Figure displays a model of PCK that acknowledges the influence of four more generic teacher knowledge domains, namely knowledge of context, knowledge of students, SMK and PK. This model is derived from the work of Davidowitz and Rollnick (2011), who identified the four knowledge domains as generalised knowledge from which a teacher draws to inform PCK. These knowledge domains have their origin in the model for PCK suggested by Grossman (1990), who suggested that these knowledge bases are influenced by the beliefs of the teacher about teaching science. This model has been chosen because the knowledge domains reflect some similar aspects to

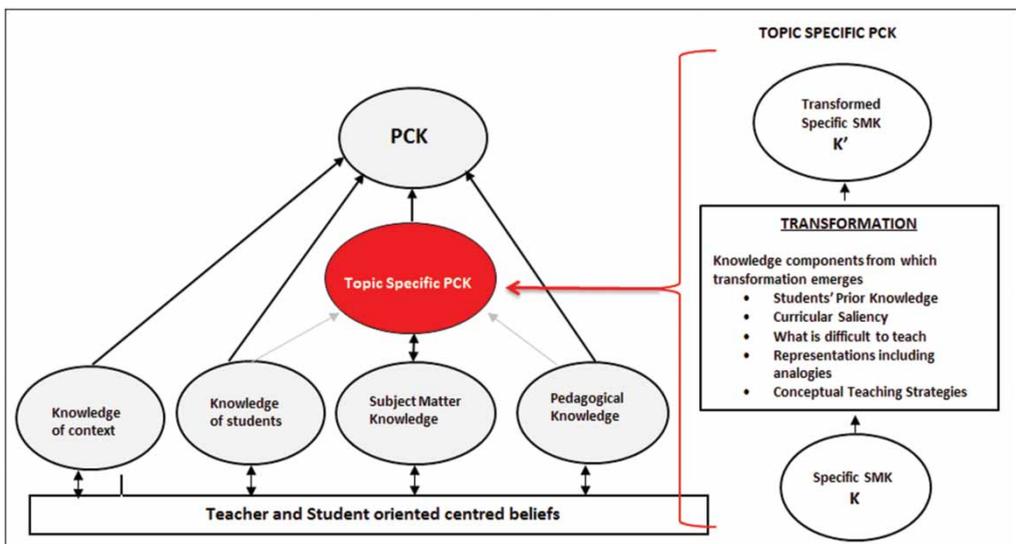


Figure 1: A model for Topic-Specific PCK

the listed content-specific components, and because it has SMK as a distinct knowledge domain. The role of SMK is crucial in the discussion of pedagogical transformation, as we assume the theoretical position that SMK is a necessary pre-requisite for the development of PCK (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008).

According to Geddis (1993), the value of focusing on the transformation of subject matter is that it directs attention simultaneously to the domain of SMK and the interactions with the listed content-specific components, as shown in Figure 1. The link between the transformation of specific SMK and PCK is through the SMK domain. As mentioned earlier, we see this interface as bringing to the fore the topic-specific nature of PCK, allowing considerations topic by topic with less attention to the full spectrum of knowledge domains influencing PCK at a generic level. Hence, we refer to this type of PCK as PCK within a topic, different from the generic type or PCK at a discipline level. The possible influence of the knowledge bases of *knowledge of students* and the *Pedagogical Knowledge* is acknowledged (faint lines) because of the relatedness of these knowledge domains to two of the specific content components, namely, students' prior knowledge and conceptual teaching strategies.

In the literature, these two content-specific components are similar to two of the five components proposed by Park and Oliver (2008) in their integration model for PCK. However, three of their components differ to those proposed in this study, in that they are not as topic specific. Park and Oliver's components include knowledge of orientations to science teaching, knowledge of science curriculum and knowledge of assessment of learning in science. Park and Oliver draw on Magnusson, Krajcik, and Borko (1999) in that their components entail teachers' knowledge and beliefs about the purposes and goals for teaching science, at a discipline level, and at a particular grade level. They have a generic nature and therefore not unique for each topic in science. Thus Park and Oliver's and Magnusson et al.'s models are not suitable for our purpose of exploring the construct at a topic level. However, similar to Park, Jang, Chen, and Jung (2011), we consider the quality of PCK within a topic to refer to both the conceptual understanding of our five content-specific components as well as their interaction.

The discussion above has presented an 'interpretive argument' for the validity of the Topic-Specific PCK construct. It provides the conceptual rationale, the expectations and the assumptions made about the construct being measured (Kane, 2006). According to Messick (1989), in addition to the interpretive argument, construct validity requires a validity argument. The validity argument provides information about the coherency and the plausibility of the interpretive argument. It may be established through statistical measurement. In this paper, the statistical argument is provided in the validation of a tool to measure the quality of the construct within chemical equilibrium, reported in another study (Mavhunga & Rollnick, 2011). For continuity, the argument is briefly recalled in the discussion of data collection below. Both the interpretive argument provided above and the validity argument discussed next, provide a comprehensive argument for the regard of Topic Specific PCK as a valid theoretical construct. As our interest lies in improving the quality of PCK explicitly within a particular topic, we specifically ask:

To what extent does the explicit teaching of transformation of concepts in chemical equilibrium through the set of five components, influence the improvement of the quality of PCK within the topic in chemistry pre-service teachers?

## Research Methodology

### *The Research Design*

As suggested by the nature of the research question, the research design was based on mixed-methods (MM). Moran-Ellis et al. (2006) argue that using mixed methods requires that different methods (or types of data) are given equal weight, and are, therefore interdependent while retaining their paradigmatic modalities. In this study, both methods have equal weight as each may capture the same or a different aspect of the research question. The design, therefore, meets the requirement for a 'parallel mixed design' (Teddle & Tashakkori, 2009). The research strategy employed in this

study is a case study, enabling targeted in-depth explorations of interactions. Merriam (2002, p. 8) describes a case study as 'an intensive description and analysis of a social unit'. The 'social unit', i.e. the sample group, is a class ( $N = 16$ ) of Secondary School pre-service teachers. These are pre-service teachers in their final year of study towards a teacher qualification—the BEd degree, with Physical Science as their major subject. The majority of the pre-service teachers come from the rural areas of South Africa. Communities in these rural areas are commonly exposed to poor education and likely to have very few science teachers with a degree qualification (SAIRR, 2012). The general understanding is that the National Department would place these final year students as qualified science teachers back in their communities on graduation. Within this context, and in the absence of nationally co-ordinated induction programmes for beginning teachers in South Africa, the development of PCK within specific topics in pre-service as discussed above is even more urgent.

### **The Intervention**

An intervention targeting understanding of transformation of Chemical Equilibrium concepts was implemented. The focus of the intervention was to develop reasoning about the topic of chemical equilibrium in terms of the five content-specific components of Topic-Specific PCK mentioned above. The intervention was structured into 12 sessions of 100 minutes each. Two sessions per week were held, extending the intervention over 6 weeks. The first and the last sessions were used for pre/post data collection through the administration of a specially designed tool for Topic-Specific PCK (discussed below). The pre-service teachers were arranged randomly into four groups which were kept unchanged throughout the sessions, as suggested by Bilgin (2006). The introductory session was used to revise the aspects contained in the theory of constructivism related to learning and teaching as well as to introduce the idea of PCK and its benefits. This introduction provided a natural flow into the discussions of the content-specific components of Topic-Specific PCK starting with that of *students' prior knowledge*. The discussions about chemical equilibrium concepts through the five content-specific components were carried out one component at a time. The teaching sessions were structured similarly. At the beginning of a session, pre-service teachers participated in a discussion of an article included as a pre-session reading task. All tasks were selected to enhance aspects of the relevant knowledge component for that session. The discussion was typically followed by explicit explanations of one of the knowledge components using central concepts in chemical equilibrium. For example, under the students' prior knowledge component, commonly reported misconceptions in chemical equilibrium were listed and discussed (Van Driel & Graber, 2002). Where participants' own knowledge was found lacking, concepts in chemical equilibrium were revised to facilitate reasoning of the concepts in terms of the content-specific components. The explanations were concluded with a class activity that illustrates the application of the specific component in a teaching situation.

Towards the end of the intervention, (session 9) Content Representations (CoRes) were introduced. CoRes are representational tools first introduced by Loughran et al. (2004) as part of a strategy to portray PCK through a series of prompts. The prompts are related to Big Ideas on a specific topic, such as 'what do you expect learners to know about this idea?' For the intervention, the CoRe was adapted to include explicit prompts on the five content-specific components. The CoRe was used in this study as a tool to capture reasoning on the five components onto a single plane. The intervention concluded with a session linking all the discussions in the intervention into the process of Pedagogical Reasoning and Action (Shulman, 1987). Emphasis was placed on the stage of transformation achieved through the collective considerations of the content-specific components discussed in the intervention.

Two additional tutorial sessions were held outside the formal class time on a voluntary basis. In these tutorials pre-service teachers responded and discussed questions posted over an interactive online platform called Blackboard ignite (BBignite). On BBignite pre-service teachers were organized in the same groups as in class and could chat to each other through written text within a group online. The questions posted were mostly seeking identification of misconceptions in chemical equilibrium and requesting suggestions for confronting them.

### Data Collection

Data were collected at key points of the study through a combination of quantitative and qualitative tools. As mentioned above, a set of pre- and post-intervention quantitative data was collected using a specifically designed Topic-Specific PCK tool for Chemical Equilibrium. The tool is structured according to the five content-specific components of Topic-Specific PCK outlined above, where each component is considered as a test item with two or three sub-questions. As alluded to earlier, we consider the understanding of each content-specific component and its interactions with other components as windows into the quality of Topic-Specific PCK. The tasks in the tool require responses from teachers that demonstrate understanding of a component as well as the pulling of one or more other components into an interplay evident in the explanations. For an example, Figure 2 presents a test item located in the content-specific component of students' prior knowledge.

The responses given as options A–C, were generated from practicing teachers during the piloting of the tool. The responses are all conceptually correct but differ in the extent of engagement with the identified misconception. Some responses, like response A and B, are limited to the provision of a theoretical definition and possibly its expansion. They show only the understanding of the content-specific component, but not the interplay of this understanding with the understanding of other components. Such responses would attract a low score. Strategies for addressing the identified misconception are likely to refer to the knowledge of the other content-specific components as is the case with response C. In response C, in addition to identifying the misconception, there is an effort to emphasize the critical feature to achieving chemical equilibrium. Here, we see a natural interplay between the components of knowing about the misconception, and elements of the component of curricular saliency where understanding of what aspect is most important for this particular case, emerges.

The design and the validation of the tool is reported in a separate study (Mavhunga & Rollnick, 2011), however a brief description is provided to strengthen the construct validity argument in this paper. The process of development followed traditionally the chronological order from (1) production of test items; (2) judgment of items; (3) construction of the instrument; (4) piloting and (5) validation of the instrument. Measurement on the reliability and validity of the tool was done using the Rasch statistical model. The

#### **CATEGORY A: STUDENTS' PRIOR KNOWLEDGE**

1. What comment would you write on a learner's script who writes:

*A reaction reaches equilibrium when the concentrations of the products and reactants are equal.*

**Response A:** No; when a reaction reaches equilibrium it does not mean the concentrations of the reactants and products are equal. The concentration of reactants and those of products are not equal at equilibrium. Sometimes the concentration of reactants is more than that of products and vice-versa. It depends on the type of reaction.

**Response B:** No; when a reaction reaches equilibrium the concentration of the products and the reactants are not equal. Equilibrium is reached when both reactions proceed at the same rate.

**Response C:** No; the concentration of reactants and products at equilibrium are not necessarily equal. Each reagent may have its own concentration which is different to the other. What ensures a reaction to be at equilibrium is the rate at which the forward and the reverse reaction occur. For equilibrium to occur this rate must be equal for both reactions.

**Response D:** None of the above

Choose your response, and use the space below to expand on your choice.

Figure 2: A sample test item from the Topic-Specific PCK tool

reliability indices as measured through person ability and item difficulty, using Rasch, were found to be acceptable at 0.88 and 0.92, respectively. All person and item measures were found to fall within the fit statistics range of +2 and -2. This indicates that both the test items and the persons' measures work coherently together to measure a single construct as intended Topic-Specific PCK, and therefore constitute a valid measure (Boone & Rogan, 2005). This analysis provides the validity argument for the construct, complementing the interpretive argument as provided earlier in the theoretical framework. Both validity arguments satisfy the requirements for construct validity as outlined by Messick (1989), and also establishes the validity of the tool, thus its use in this study.

The scoring of the responses of the pre-service teachers from the tool was done using a criteria-based ordinal rubric. The rubric has the five content-specific components with each being rated on a four point scale from a minimum of 1 'Limited' to a maximum of 4 'Exemplary' (Park et al., 2011). Similar to the emphasis in the tool, the criteria for the category of 'Exemplary' in the rubric called for evidence of the natural interplay of components in addition to the knowledge in each component, see sample in Figure 3 below. As the questions from the tool offered additional opportunity for the respondents to explain their choices, these were considered in the scoring as some of the criteria may be embedded in the explanation. For example, respondents may offer a response that illustrates a correction strategy that reflects a natural interplay of content-specific components other than those reflected in the provided response choice.

As the intervention unfolded session by session, various qualitative data capturing strategies were used, including photographic capturing of written class activities, audio recordings of class discussions in their groups, developed CoRes and teacher outlines; written text of the discussions over the interactive online BBignite platform; and copies of student assignments. Similar to the quantitative data, emphasis in the analysis of the qualitative data was placed on evidence of the understanding of a content-specific component and its interplay with other components.

## Findings

### Quantitative Analysis

Given that the responses in the Topic-Specific PCK tool were scored using a four point rubric, the data obtained were of an ordinal type where the intervals were not necessarily equally spaced. For this reason, the raw scores were converted into Rasch measures (Boone & Rogan, 2005) that are placed on a scale with equidistant intervals. The Rasch model places persons' ability measures on the same interval scale as the measures for items' difficulty. This assists in determining internal coherency and in establishing rank order of persons' ability and item difficulty measures. Thus two sets of topic-specific PCK quantitative data were generated for the pre and post-tests respectively (as shown in Table 1). The Rasch measures generated from these scores, produced acceptable person and item reliability indices in both tests. In the case of the pre-test, the person reliability was 0.65 and item reliability of 0.96. For the post test, the person reliability was 0.73 and item reliability of

TSPCK Components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
Students' Prior Knowledge including misconceptions	No identification No acknowledgement No consideration of students' prior knowledge or misconceptions	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> <li>Repeats standard definition with no expansion or with incorrect explanation</li> </ul>	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> <li>Expands and re-phrases explanation correctly</li> </ul>	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> <li>Expands and re-phrases explanation correctly</li> <li>Confronts misconceptions/confirms accurate understanding with using a specific conceptual teaching strategy or knowledge of representations or elements of curricular saliency</li> </ul>

Figure 3: A sample extract of the Topic-Specific PCK rubric

**Table 1:** Raw pre and post-test scores per content-specific component

No.	Pre-service teachers	Students* prior knowledge		Curricular saliency		What is difficult to teach?		Representations		Teaching strategy	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		1.	PM	3	3	2	3	3	3	2	3
2.	SM	3	4	2	4	4	3	1	4	1	3
3.	PPM (group 1)	4	3	1	3	3	3	1	3	1	3
4.	TSM	3	4	3	2	3	2	1	2	1	3
5.	IDL	3	4	2	3	2	2	1	1	1	3
6.	BM	4	3	1	3	2	3	1	3	1	1
7.	NG	3	3	1	3	3	2	1	1	1	1
8.	PMT	3	4	2	3	2	4	1	4	1	3
9.	LLM	2	3	2	2	2	2	1	1	1	1
10.	KGS	3	4	1	3	2	2	1	4	1	2
11.	JS (group 1)	3	3	1	2	1	3	1	2	1	1
12.	MC(group 1)	2	3	1	3	2	3	1	4	1	3
13.	MM (group 1)	2	2	1	2	2	3	1	2	1	2
14.	BS	2	2	2	3	2	3	1	2	1	2
15.	zs	2	1	1	2	1	3	1	1	1	1
16.	KM	2	3	1	3	1	3	1	3	1	1

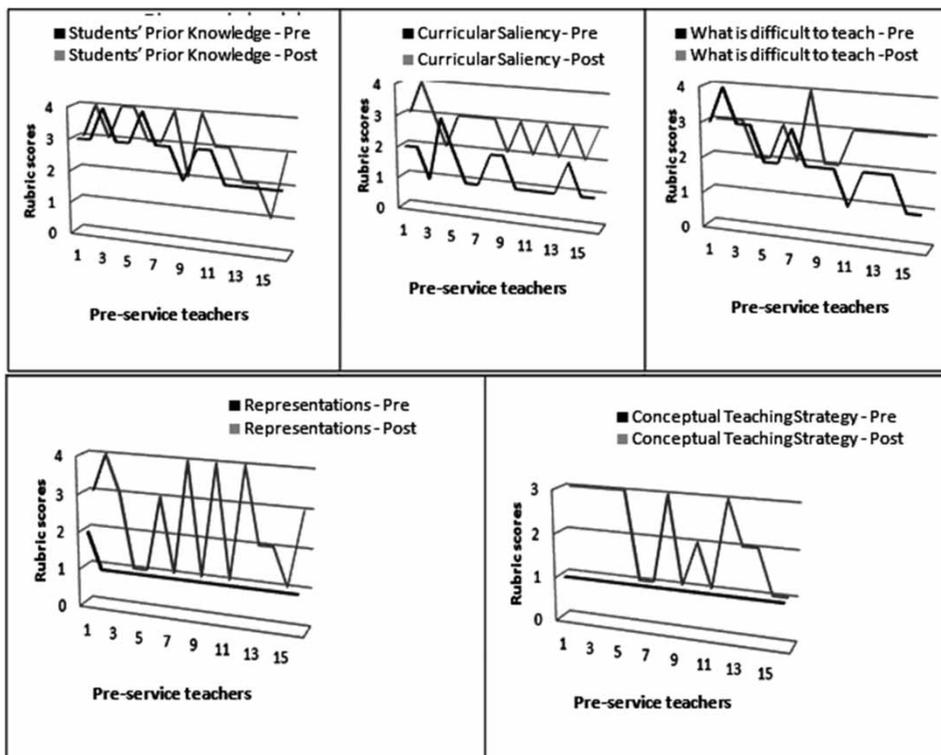
\*The term student is used in the actual tool to refer to the component of Learner Prior Knowledge.

0.76. In both cases the item and measured person scores reflected error estimates well inside the conventionally acceptable fit statistics range of  $-2$  and  $+2$ , indicating good validity. The fact that these reliability and validity indices are within the acceptable range, is a further evidence of the validation of Topic-Specific PCK as a construct.

In order to compare shifts between the pre and post-tests, it is necessary that the pre/post-tests are first equated (Wright, 1996). One of the ways of equating a test in the Rasch statistical model is to use a fixed base procedure—also known as anchoring. In this study, the pre-test was regarded as the base test and its item difficulty measures anchored and used to equate the scale of the post-test. The person ability measures from both tests were then positioned on a similar frame and compared using a non-parametric Wilcoxon Paired Signed Rank test for analysis for significance difference in order to suit the limited sample size of the study. The comparison yielded a significant difference between the tests at 99% level of confidence. This finding provides an overall impact of the intervention. It indicates that pre-service teachers experienced an improvement in the quality of PCK specifically in Chemical Equilibrium. Thus they have improved their ability to reason about the topic in ways that consider its teachability. This result emerges from the collective effect of the five content-specific components.

It is however, equally important to determine the extent of improvement (learning) in each of the five components. Figure 4 presents a visual display of the raw scores when compared as pre vs. post-test per component. Scanning the graphs through visual inspection, it appears that there was a varying increment across the content-specific components. However, most learning is registered in the components of Representations and Conceptual Teaching Strategies, followed by Curricular Saliency.

The above trend is further confirmed by the test item difficulty values for both pre- and post-tests generated in Rasch, Table 2. Higher numerical values reflect increased difficulty. In the pre-test, pre-service teachers found the topic difficult in terms of the components of curricular saliency, representations and conceptual teaching strategies difficult in the given order. However, in the post test, there is a visual decrease in the values of item difficulty across all items, meaning that the extent of difficulty was generally decreased after the intervention. This observation signals an improvement of learning in varying degrees across all these components, with most learning registered in the components of Representations and Teaching Strategies.



**Figure 4:** Graphical representations of the pre/post-test scores per content-specific component

**Table 2:** Rank order of Topic-Specific PCK test items

Topic Specific PCK Test	Students' Prior knowledge	What is difficult to teach	Curricular Saliency	Representations	Teaching Strategies
Pre-test	0.50	0.51	0.60	5.06	6.43
	LPK <	WDT <	CS <	R <	TS
Post-test	-1.29	-0.48	-0.12	0.38	1.52
	LPK <	WDT <	CS <	R <	TS

Item measure mean set to zero & Units per Logit = 1 for the entire test (UIMEAN = 0 and USCALE = 1). Symbol ' <' means less difficult than.

### Qualitative Analysis

The analysis of qualitative data collected during the teaching sessions indicates a number of cases where both the improvement in the understanding of a content-specific component as well as its natural interplay with other components happened simultaneously. Because space limitations, the analysis below is limited to evidence in two of the five content-specific components, given below as scenarios 1 and 2. Examples chosen are in the components of students' prior knowledge and conceptual teaching strategies respectively, as these two components are reported to be common in most other qualitative PCK tools (Park et al., 2011). In this study, they respectively represent the least and the most difficult test item. The work of one group, marked in Table 1 above, was chosen for both scenarios to provide a sense of continuity.

### Scenario 1: Students' Prior Knowledge

Given below is an extract from the text messages that students exchanged during a discussion on the BBignite platform. The discussion occurred immediately after the teaching of the component of student's prior knowledge. Figure 5 shows a chemical equation with unequal double arrows posted on BBignite. Pre-service teachers were requested to share their understanding, as they reasoned through the meaning expressed by the equation.

Following below are the extracts of the discussions within a group—from student MM:

*In actual fact the double unequal arrows is another way of explaining that both sides of the equation are in equilibrium. ... for example arrows visually appear to be unequal or longer than each other, learners may think that the longer arrow for example that is pointing forward means the forward reaction is faster than the shorter arrow that is pointing backward.* [BBignite, student MM]

Student MM's conception of the meaning of reaction arrows appears to be in place, as seen from his confirmation that the reaction is at equilibrium despite the unequal lengths of the arrows. However, he does not provide a specific statement directed at the meaning of the unequal arrows. Nonetheless, he demonstrates understanding that the use of the unequal double arrow has potential to introduce a misconception about equilibrium having different rates. This is a reflection of some understanding about common misconception in the topic—an aspect of the component of learners' prior knowledge. Student MM, however, continues to refer to an aspect of teaching not under current discussion suggesting a representation to introduce the concept.

*..To introduce this lesson, I can use the teaching aid as the seesaw with two people of the same mass of each side.* [BBignite, student MM]

This observation points to an emerging effect, where while the focus is on reasoning about one content-specific component, considerations about the knowledge of another is naturally made. The extract displays evidence of both the understanding of a component (learners' prior knowledge) and the interplay with another (use of representations).

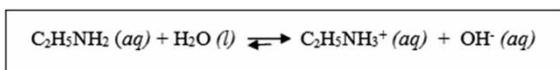


Figure 5: A reaction at equilibrium expressed using double arrows that are unequal

### Scenario 2: Conceptual Teaching Strategies

Evidence of understanding in this component is best seen through the suggestions made in the developed CoRes, particularly a sample outline of a lesson on one of the big ideas suggested in the CoRe. The CoRe and the sample lesson outline were submitted as part of a major class assignment. Illustrated below is an extract from student MC's lesson outline (see Table 3).

This is an extract of a lesson outline building towards the understanding of dynamic chemical equilibrium. The manner in which the intentions of the lessons are written provides a sense of the awareness of the common misconception about equal concentration of reactants and products at equilibrium. Standard definitions in most school textbooks do not mention the aspect about the 'concentration', rather emphasise 'equal rates', therefore the awareness demonstrated by the phrase '*chemical equilibrium in terms of concentration not rates*' is original. The deliberate omission of the phrase 'rates' in the definition is a demonstration of increased knowledge of aspects of curricular saliency knowing what to say when and knowing what to leave out. The second aspect illustrated in the extract is the sense of sequencing. The discussions are to follow a particular order that strategically builds from one concept into another. Sequencing for conceptual understanding is another important aspect of curricular saliency. Choosing to use a practical demonstration illustrating a feature of chemical equilibrium is similar to the suggestions made by Tyson et al. (1999) and by Van Driel and Graber (2002) as a

**Table 3:** An extract from student MC's lesson outline based on a CoRe

Big idea: What is Chemical Equilibrium?	
Lesson 1	
Sub-concepts covered	What is meant by Chemical Equilibrium? Open and Closed systems Reversible reactions Dynamic and physical Equilibrium
Brief outline of how intentions of lessons are covered, highlighting TSKFT to be used in lesson	I will prompt learner's prior knowledge by Questioning, and then I will move on to chemical equilibrium definition in terms of concentration of reactants and products not rates. I will then move to open and closed systems (Highlighting where Chemical Equilibrium occurs—by using resources to ask learners the difference between what is viewed as open and what is viewed as closed system) Lastly I will move or to demonstration by boiling water (in a sealed see through pot) in class and asking learners question in relation to what they are observing. For learners to draw the system, to predict whether it is closed or open by asking questions like is matter lost in this system or does the mass of the system changed as this pot is sealed?

teaching strategy to confront certain misconceptions in this topic. There is a further hint on asking learners to make drawings of the system although it is not clear what level of representations is aimed at. Nonetheless, the extract displays evidence where the initial focus is on one content-specific component, in this case conceptual teaching strategies, and the interplay with other components naturally emerged.

### Discussions and Conclusion

Our discussion began with the notion of locating PCK at a topic level. We acknowledged its topic-specific nature as reported in the literature, however, argued for a refined definition sensitive to the transformation of topic concepts. By emphasising the transformation of topic concepts, a different kind of discussion ensued which is not about the SMK of the topic *per se* but about the kind of knowledge needed to teach the SMK of the topic. Such a discussion references knowledge components that we termed content-specific components, and also acknowledged their transformative effects on the SMK of the topic. Following an intervention where a discussion of the topic of chemical equilibrium in terms of the topic-specific components was explicitly held, the analysis of both quantitative and qualitative data provided an answer to our specific question. It indicated that the quality of Topic-Specific PCK, as a theoretical construct located within a topic, may be improved significantly through such explicit discussions. The importance of this finding among other things is the evidence of a concrete reciprocal relationship, between PCK and pedagogical transformation, where the latter was previously reported to emerge from PCK (Shulman, 1987). This offers a possible useful framework to develop the capacity to think about concepts topic by topic in specific ways that transforms and re-packages them with teaching in mind.

The purpose of the findings signal improved thoughts by pre-service teachers about the teaching of chemical equilibrium concepts. These thoughts now exist prior to the actual act of teaching the topic. According to Shulman (1987), pedagogical reasoning 'is as much part of teaching as is the actual performance itself'. In general practice, such reasoning is reported to develop with time in a practice full of reflection in and on action (Nilsson & Loughran, 2012). It is therefore recommended that implementation of PCK in teacher education programmes be defined and packaged at a topic level as shown in this study. For teacher education programmes in the South African context, this approach has

promise for producing teacher graduates who have exposure to such reasoning at least in a selection of core science topics.

For practicing teachers, professional support programmes may be structured to develop PCK in one topic at a time, rather than placing emphasis overwhelmingly at the discipline level.

As the study has the limitations of sample size and, therefore, generalisation is limited, we recommend that research in this area be extended to include other topics and to consider implementation of the construct in large-scale research projects.

## Note

1. In this article Subject Matter Knowledge (SMK) is to be read synonymous with Content Knowledge (CK).

## References

- Abell, S. (2007). Research on science teacher knowledge. In S. Abell & N. Lederman (Eds.), *Handbook of research in science education* (pp. 1105–1150). Mahwah, NJ: Lawrence Erlbaum.
- Ball, D., Thames, M., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, 59, 389–407.
- Bergquist, W., & Heikkinen, H. (1990). Student ideas regarding chemical equilibrium. *Journal of Chemical Education*, 67, 1000–1003.
- Bilgin, I. (2006). Promoting pre-service elementary students' understanding of chemical equilibrium through discussions in small groups. *International Journal of Science and Mathematics Education*, 4(3), 467–484.
- Boone, W., & Rogan, J. (2005). Rigour in quantitative analysis: The promise of Rasch analysis techniques. *African Journal of Research in Mathematics, Science and technology Education*, 9(1), 25–38.
- Davidowitz, B., & Rollnick, M. (2011). What lies at the heart of good undergraduate teaching? A case study in organic chemistry. *Chemical Education Research and Practice*, 12, 355–366.
- Department of Education. (2000). *Norms and standards of educators*. Pretoria. Retrieved 5 November 2012 from [www.education.gov.za](http://www.education.gov.za)
- Geddis, A. (1993). Transforming subject-matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education*, 15, 673–683.
- Geddis, A., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education*, 13(6), 611–626.
- Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York, NY: Teachers College Press.
- Jüttner, M., & Neuhaus, B. (2012). Development of items for a pedagogical content knowledge test based on empirical analysis of pupils' errors. *International Journal of Science Education*, 34(7), 1125–1143.
- Kane, M. (2006). Validation. In R. L. Brennan (Ed.), *Educational measurement* (4th ed., pp. 17–64). Washington, DC: Praeger.
- Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education*, 45(2), 169–204.
- Loughran, J., Berry, A., & Mulhall, P. (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.
- Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature sources and development of pedagogical content knowledge for science teaching. In J. Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Dordrecht: Kluwer Academic.
- Mavhunga, E., & Rollnick, M. (2011). *The development and validation of a tool for measuring topic specific PCK in chemical equilibrium*. Paper presented at the ESERA Conference, Lyon, France.
- Merriam, S. B. (2002). *Qualitative research in practice: Examples for discussion and analysis*. San Francisco: Jossey-Bass.
- Messick, S. (1989). Meaning and values in test validation: The science and ethics of assessment. *Educational Researcher*, 18(2), 5–11.
- Moran-Ellis, J., Alexander, V., Cronin, A., Dickinson, M., Fielding, J., Slaney, J., & Thomas, H. (2006). Triangulation and integration: Processes, claims and implications. *Qualitative Research*, 6(1), 45–59.
- Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education*, 30(10), 1281–1299.

- Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education*, 23, 699–721.
- Park, S., Jang, J.-Y., Chen, Y.-C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching? Evidence from an empirical study. *Research in Science Education*, 41, 245–260.
- Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education* 38, 261–284.
- Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching amount of substance and chemical equilibrium. *International Journal of Science Education*, 30(10), 1365–1387.
- SAIRR. (2011). *South Africa Survey 2010/2011: Education*. Johannesburg: South African Institute of Race Relations.
- SAIRR. (2012). *Unemployment: Progress at last, maybe fast facts*. Johannesburg: South African Institute of Race Relations.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14.
- Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1–22.
- Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Thousand Oaks, CA: Sage.
- Tyson, L., Treagust, D. F., & Bucat, B. (1999). The complexity of teaching and learning chemical equilibrium. *Journal of Chemical Education*, 76(4), 554–557.
- Van Driel, J. H., & Graber, W. (2002). The teaching and learning of chemical equilibrium. In J. Gilbert, O. De Jong, R. Justi, D. Treagust, & J. Van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 271–292). London: Kluwer.
- Veal, W. R., & Makinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education*, 3(4), 1–18.
- Wright, B. D. (1996). Reliability and separation. *Rasch Measurement Transactions*, 9, 472. Retrieved 11 October 2012 from [www.rasch.org/rmt/rmt94n.htm](http://www.rasch.org/rmt/rmt94n.htm)