EXPLICIT INCLUSION OF TOPIC SPECIFIC KNOWLEDGE FOR TEACHING AND THE DEVELOPMENT OF PCK IN PRE-SERVICE SCIENCE TEACHERS

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1. **INTRODUCTION**

Is there a magic teaching formula to produce beginning science teachers that creates coherent, meaningful and rich lessons for their students? All things being equal, it is intuitively understood that beginning science teachers, as well as pre-service teachers, rarely display the level of competency seen in seasoned teachers (Gess-Newsome, 1999a), especially with regard to effective integration of science content knowledge and teaching. Research suggests that even with improvement in both subject matter knowledge and pedagogical knowledge, pre-service teachers appear unable to integrate these domains (Lederman et al., 1994). Furthermore, their science subject matter knowledge is reported to be fragmented, compartmentalized, and poorly organized, making it difficult to access it efficiently when teaching (Gess-Newsome, 1999b, p. 63). Also pre-service teachers tend to focus on teaching facts and algorithms, paying little or no attention to conceptual aspects of learning and understanding by students. Luft (2009) argues that the realization that the understanding by students is the centre of teaching, is associated with responsive and reformative teacher beliefs. Teachers without these beliefs tend to make instructional choices that are static and teacher-centred in nature and are highly unlikely to engage in the re-organization and re-construction of their instructions for student understanding. A study by Ogan-Bekiroglu and Akkoç (2009) reveals that pre-service teachers are often not even aware of their own beliefs. Therefore, the choice of ineffective instructional strategies by pre-service teachers may continue unconsciously unless this is pointed out to them. Compounding the problem is the observation that even those who have proclaimed beliefs that are responsive (in line with student-centred learning), display inconsistencies between their own beliefs and classroom practices (Lee, Luyk, Buxton and Shaver, 2007). Given the above state of affairs, it follows that the kind of competency leading to understanding by learners, as called for by Shulman, is a gem rare to find in beginning teachers. Shulman spoke in the 1980s against the selective emphasis on general classroom pedagogy over subject matter knowledge in teacher expertise research studies. He stated, ‘no one asked how subject matter was transformed from the knowledge of the teacher into content of instruction’ (Shulman, 1986, p. 6). He argued that teaching draws on a complex amalgam of different knowledge domains where both pedagogy and subject matter knowledge are included. He introduced Pedagogical Content Knowledge (PCK) as a term referring to desired competency in teaching. Central to the concept of PCK is the capacity by teachers to transform their comprehension of SMK into forms that are
understandable to learners. Such capacity is observed in teachers who display evidence of PCK. This study focuses on the articulation of the knowledge needed to enable pedagogical transformation and the reciprocal effect of such knowledge in developing PCK in pre-service teachers.

2. PURPOSE OF RESEARCH

The purpose of the study is to determine the feasibility of fast-tracking the development of PCK in high school chemistry pre-service teachers. It is argued that by explicitly introducing knowledge needed to transform subject matter content for a given topic when the subject matter content is taught, both the opportunity for understanding of subject matter and the capacity to transform it for teaching purposes will increase. Knowledge needed for transforming subject matter content for a given topic refers to the broad category of knowledge types from which pedagogical transformation emerges, referred to as knowledge for teaching. The study will investigate the effect of teaching Chemical Equilibrium to pre-service teachers, with explicit discussions of knowledge needed for transforming it for purposes of teaching. It is envisaged that the findings of this study will contribute to both the limited understanding of the development of PCK in pre-service teachers and the shortening of the extended PCK development trajectory currently experienced by beginning teachers. Furthermore, it is envisaged that a PCK tool that measures the quality of the captured PCK will be developed. The tool will help to minimize the paucity of such tools and may be used in furthering research in the development of PCK in pre-service teachers.

3. RATIONALE

As indicated above, there is increasing realization that PCK is poorly or not developed at all in beginning science teachers (Luft, 2009; Lederman et al., 1994; Verloop, 1992), and therefore in pre-service teachers. This realization is further confirmed in a study of 24 secondary beginning science teachers (Lee et al., 2007). The authors report that even in the presence of strong science subject matter background, proficient PCK is not guaranteed. It appears that such expertise comes through practice and a concerted effort of trial and error leading to improvement through reflection and insight (Loughran et al., 2006). Thus, it appears that the development of PCK is an individual journey to be repeated by each generation of beginning teachers. Also, its success depends on individual motivation and persistence with trial and
error practices. Other than that, it depends on hope for accessing mentoring support. Previous research suggests that in the absence of early career support such as an induction programme, beginning science teacher practices offer few opportunities for students to engage in inquiry (Luft, Roehrig, & Patterson, 2003). Teachers rely on algorithms and therefore there are no opportunities for students to benefit from PCK rich lessons. Such traditional practices and therefore the lack of PCK may persist for years to come (Luft, Roehrig, & Patterson, 2003). When relating the findings associated with the lack of early career support in a country like South Africa, they confirm the current widely known reality. The National Policy Framework for Teacher Education and Development in South Africa (DoE, 2007) recognizes the challenges facing teacher development, but is silent on teacher induction programmes as a development strategy for beginning teachers. In other words, the country has no nationally coordinated support for beginning teachers. Even after many years of practice, teacher development initiatives are sporadic, un-coordinated and found to be non-effective (Taylor & Vinjevold, 1999, Erasmus & Mda, 2008). Studies also reflect a prevalence of under-qualified science teachers, most of whom lack science degrees in their qualifications. Some of those with a science degree teach in subjects other than their qualification majors (Carnoy & Chisholm, 2008). The inadequacy in subject matter understanding is a major disadvantage in developing PCK, since subject matter knowledge is a pre-requisite to PCK development (see discussions in Literature Review). It stands to reason that not only will beginning science teachers in South Africa suffer from a lack of PCK, as is the case with their counterparts in other countries, but will have little or no chance to develop it outside their pre-service programmes. As a consequence, the kind of rich science teaching, and the resulting conceptual understanding by learners, on a scale of mass education as envisioned in our Constitution (Act No.108 of 1996) is a mission impossible’. The need to develop PCK in science teachers is vital in South Africa. At present, the most feasible avenue for developing such expertise is within the pre-service programmes offered by Higher Education Institutions. It is in the education policies of these institutions that the post-apartheid education reform created opportunities to significantly influence the official knowledge for teachers and teaching (Parker and Adler, 2005, pg. 61). The findings of this study will not only be relevant to addressing the case in South Africa, but will contribute considerably to the international subject of PCK development in pre-service teachers, a field under development.
4. LITERATURE REVIEW

The starting point of this study is the acknowledgement of Shulman (1986) theoretical idea, that teaching requires transformation of knowledge from a variety of domains among which subject matter knowledge is central. It also proposes that PCK, as seen in seasoned teachers, is the amalgam of knowledge that enables such transformation to materialize. This literature review builds on this conception and presents a case for considering development of PCK as a goal in science teacher education. The review begins by presenting reasons for the feasibility of developing PCK in pre-service teachers. It then extends into findings from previous research studies regarding factors influencing the development of PCK. Emphasis is placed on the relationship of PCK with Subject Matter Knowledge (SMK), with Teaching Experience and with Beliefs. The discussion then explores the competencies of expert teachers with developed PCK in a topic. The reciprocal development of PCK through teaching knowledge that enables competencies associated with the presence of PCK in pre-service programmes is discussed. The resulting conclusions are synthesised into a proposed theoretical framework and a corresponding intervention.

4.1 PCK in Pre-service teachers – is it a reasonable expectation?

The central tasks of pre-service teacher programmes, according to Feiman-Nemser (2001), are to build on 'what teachers need to know, care about and able to do in order to promote substantial learning to all students' (p. 4). She presents five tasks that she considers central to the function of a pre-service programme. These are: (i) analyzing beliefs and forming new visions, (ii) developing subject matter knowledge for teaching, (iii) developing understandings of learners and learning, (iv) developing a teaching repertoire and (v) developing the tools for studying teaching. Together these tasks form a coherent and dynamic agenda for the initial preparation. However, she further argues that the pre-service stage by itself is not sufficient to produce teachers with desired qualities of teaching. She lists further stages beyond pre-service, namely, induction and in-service stages. According to Feiman-Nemser (2001), the induction and in-service stages have a set of development goals that, while different from each other and to the pre-service stage, addresses the needs of teachers at different stages of their career. Therefore, the development of a teaching career is a life-long continuum. While this view has been supported by previous research studies that have reported inefficiencies in pre-service teachers (Lederman et al., 1994; Verloop, 1992; Huberman, 1989; McDonald, 1980; Ryan, 1970), there is emerging research indicating that certain teacher education programmes are
producing newly qualified teachers who “can act on their commitments; who are highly knowledgeable about learning and teaching and who have strong practical skills,” despite being beginning teachers (Darling-Hammond, 2006a, p. 5). The work by Darling-Hammond (2005; 2006a; 2006b) explores characteristics of ‘powerful’ teacher education programmes that produce sought-after, competent graduating teachers. Her findings highlight the importance of a tight coherence and integration between courses within a teacher education programme, and strong links between these courses and teaching experience. Such findings point to the feasibility of producing pre-service teachers with highly desirable teaching qualities, including PCK. The statements by Kind (2009) and Sanders et al. (1993) provide further reasons for reasonably expecting PCK development in pre-service teacher programmes. They both reported that pre-service teachers may be more willing to learn PCK for teaching outside their area of specialization than experienced teachers. A teacher with well established, good PCK relating to one specialist subject experiences uncertainty and hesitation when faced with teaching new, unfamiliar subjects or even unfamiliar topics within their subject area (Rollnick et al., 2007). A pre-service teacher with no prior PCK on which to draw is more open to developing PCK across science specialist subjects (Kind, 2009). Therefore, pre-service teacher education programmes provide a fertile ground to develop PCK. Returning to the central tasks of a pre-service programme as outlined by Feiman-Nemser earlier in this section, while I am in agreement with the listed tasks of a pre-service programme, I would however like to insert the ‘development of PCK’ as an additional central task. Following below the nature of PCK with respect to SMK, teaching experience and beliefs are explored.

4.2 The Nature of PCK

PCK has an elusive nature. It is tacit, hidden, knowledge. When preparing lessons, for example, teachers think pragmatically: ‘I am preparing a lesson’ not, ‘I am using my PCK’ (Kind, 2009; p. 170). Pedagogical content knowledge is not (yet) an explicit tool used consciously by teachers. One of the aspirations of this review is to highlight factors reported to influence its development and to begin to understand the impact of implementing these on the development of PCK in pre-service teachers. Despite its difficult tacit nature, a widely agreed claim arising from research is that PCK provides a useful theoretical framework for understanding and developing teachers’ competence (Abell, 2008).
4.2.1 PCK and Subject Matter Knowledge

Rollnick et al. (2008) and Childs and McNicholl (2007) reported similar findings that when a teacher was secure in her SMK, she could explain the science concept she was teaching more fully and accurately, resorting less often to simplistic dialogue. When teaching topics in which she expressed less confidence in her SMK, students were forced to learn by factual recall and information from experiments. Sperandeo-Mineo et al. (2006) used the macro-micro shift applied to thermodynamics as the subject context for their PCK development study, and reported finding that pre-service teachers show the same learning difficulties and representations as school students. The authors suggest that knowledge transformation is not a one-way process from SMK directly to PCK. They suggest a two-way process, pointing out that SMK differs between teachers, as will learners’ interpretations of what is presented to them. Hence, successful knowledge transformation depends on teachers having a deep knowledge of physics as well as an awareness of the pupils’ spontaneous models in the different content areas (p. 238). Halim and Meerah (2002) studied the PCK utilized for teaching physics concepts by 12 pre-service teachers with varied science degree backgrounds. They found that a majority of trainees held misconceptions similar to school students. When teaching, trainees repeated their own misunderstandings; their ability to transform SMK for students was impeded (p. 223) by their lack of knowledge. Van Driel, de Jong and Verloop (2002) and de Jong and van Driel (2004) draw similar conclusions. They investigated how pre-service chemistry teachers teach topics involving the macro-micro shift—the relationship between observable phenomena and the particulate nature of matter. Results showed that a university-based workshop and high quality mentoring helped trainees become more aware of their tendency to jump between macro and micro levels without considering the impact of this on students. The authors report that following the workshop intervention, evidence of developing PCK was noticed in that trainees were more able to consider students’ needs in preparing teaching strategies. From these studies, good subject matter knowledge is identified as an important factor. I would add that it seems to be a necessary pre-requisite for the development of PCK. Veal, Tippins and Bell (1999) suggest that PCK development is complex, occurs in phases and relates to trainees’ abilities to integrate knowledge from a variety of sources. While possession of good subject matter knowledge is identified as essential to PCK development, the authors further report that classroom experience may be another influential factor.
4.2.2 PCK and Classroom Experience

Veal, Tippins and Bell (1999) monitored PCK of beginning science teachers using a series of content-specific vignettes, among other methods. They found that PCK developed over time, with participants reporting classroom experience as the most important influential factor. A Taiwanese case-study, conducted by Tuan, et al., (1995) traced the development of PCK of three pre-service chemistry teachers during their one year teacher education course for factors influencing the development of their PCK. The authors report that, at first, the teachers held hierarchical subject matter structures based on their own school education, in that they perceived chemistry as a subject comprising layers of successively more difficult and complex concepts. They had been taught in a highly structured format starting with the least complex concepts, building towards the most complex as earlier ones were mastered. This shifted to making more connections with other disciplines and to everyday life towards the end of the training course. Initially, these teachers’ PCK was primitive, relying on repetition of information. Later on, more evidence of rich PCK was displayed. The recommendation from these studies highlights the importance of exposure to real classroom experience by pre-service teachers. A similar observation was made by Luft (2009), where beginning teachers were supported through an induction programme for a period of a year. Their PCK is reported to have strengthened in the area of student learning which the author attributes to working with students in their classrooms, becoming more cognisant of their students’ learning, and adapting their instruction accordingly. However, Tobin and Garnett (1988) warned that classroom exposure is no guarantee to the creation of an ‘expert’. Lee et al., (2007) demonstrated that insights into PCK could be developed through a process that focused on the planning and enactment of a lesson. However, this finding does not counteract the identification of classroom exposure as a part of a coordinated and integrated pre-service programme called for earlier by Darling-Hammond (2006a; 2006b), as one of the factors with influence on the development of PCK. A cue is taken from the review of the above research studies of the potential value of a research design for insight into the development of PCK, that has the planning of a lesson and its enactment integrated.

4.2.3 PCK and Beliefs

In addition to good SMK and classroom exposure discussed above, the extent to which pre-service teachers learn and practice what they have been taught is reported to be linked to the beliefs they hold about teaching and teaching science. In science education, research on beliefs has been linked to the use of inquiry, national reforms, or constructivist practice in the
classroom (e.g., Hashweh, 1996; Tsai, 2002; Wallace & Kang, 2004; Yerrick, Parke, & Nugent, 1997). Luft and Roehrig (2007) identified five categories of teacher beliefs, namely, traditional, instructive, transitional, responsive and reform-based. Traditional and instructive responses represent teacher-centred beliefs, while responsive and reform-based responses represent student-centred beliefs. Transitional responses reflect a view of students that focuses primarily on their behaviourist and affective attributes and not always their cognitive involvement. The authors found that beginning science teachers have beliefs that are aligned with traditional epistemologies and that these beliefs may be resistant to change and not easily impacted by the pre-service program. Another discovery was that teachers form peripheral beliefs that are slow to change. The finding is similar to that of Veal (1999) who looked at beliefs of science teachers and noted that these relate to their original learning experience and views about how abstract or ‘magical’ a particular concept or event was. Veal notes that to develop PCK, changes to these often deep-seated beliefs are required. The influence of beliefs on the development of rich PCK will be of interest to this study.

4.3 The benefits of developed PCK

In cases where all the above influential factors, and perhaps additional others, are in line and complement each other to yield a PCK presence, how do teachers use this rich expertise? According to Shulman (1987), the benefit for teachers with PCK, is their capacity to transform their comprehension as they pedagogically reason about their teaching. He described transformation as ‘the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students’ (p. 15). The idea of teaching involving transformation of SMK has been supported by a number of researchers (Geddis and Wood, 1997; Abd El-Khalick, 2006; Rollnick et al., 2007; Gess-Newsome, 1999b). In exploring the epistemological aspects of PCK, Gess-Newsome (1999b) described two models that expert teachers may use to process their knowledge for teaching - the integrative model and the transformative model. For the purpose of this study, focus will be placed on the transformative model. The transformative model presents PCK emerging from the amalgam of all knowledge needed in order to be an effective teacher. Knowledge of subject matter, pedagogy, and context is transformed into a new version of knowledge that is more effective for teaching than its constituent parts. This model is also described by Bishop and Denley (2007) in a form of an analogy of a top with different colours representing the different knowledge domains. When, spinning, the colours of the top are mixed portraying one single colour, of the PCK. The
implication for pre-service programmes is that there is a need to explicitly develop the view that teaching is about purposeful transformation of teacher knowledge for the benefit of learners (Geddis, 1993). Geddis (1993) further asserts that once this view about transformation has been developed, it is important to *articulate the knowledge needed to perform such a transformation* (p. 675). While the transformation model is widely accepted as a mechanism for the emergence of PCK, it is, however, not fully developed to define the knowledge needed to effect the transformation itself. It is envisaged that, when the needed knowledge has been fully articulated, it may be taught in pre-service programmes, thereby accelerating the capacity to pedagogically transform SMK and reciprocally developing the PCK of pre-service teachers. This study is an attempt to posit the nature of the needed knowledge for transformation of SMK in science and investigate the effects of the posited knowledge in developing PCK in science pre-service teachers. The discussion below presents the conceptual articulation of knowledge needed for transformation of SMK in science, specifically chemistry.

### 4.4 The Knowledge Needed to Effect Transformation of SMK

In order to articulate the knowledge enabling transformation of SMK, the base used by the teacher as a foundation for her knowledge is first described. Shulman (1987) presented seven categories of knowledge as a minimum base thus used. The description of these categories has been extracted and adapted from Rusznyak, (2008, p. 99) and summarized below:

*Content knowledge*

Content Knowledge (CK), a term used by Shulman to refer to the *amount* and *organization* of knowledge per se (Shulman, 1986, p. 9). CK, according to Shulman, has three distinguishable categories, namely, subject matter knowledge, pedagogical knowledge and curriculum knowledge. In his description of CK, he refers to *going beyond knowledge of the facts or concepts of a domain. It requires understanding of the structures of the subject matter*’ (Shulman, 1986, p. 9). However, when describing the categories of knowledge needed by a teacher, Shulman separates each of the categories and discusses them as stand-alone categories. In this set of categories, content knowledge is used as an entity equivalent to SMK. Content Knowledge then refers to knowledge and understanding of the central concepts, factual information and organizing principles that make up a discipline, an understanding of the big ideas and productive patterns of thought within the discipline, and understanding how new
knowledge in the field is acquired, analyzed and validated (Grossman, Wilson & Shulman, 1989).

**General pedagogical knowledge**

General pedagogical knowledge is defined as the "broad principles and strategies of classroom management and organizational that appear to transcend subject matter," and is applicable across grades (Shulman, 1986). Such knowledge includes ways of maintaining appropriate discipline, using class time efficiently, and communicating instructions / expectations clearly.

**Curriculum knowledge**

Shulman (1986, p. 10) maintains that curriculum knowledge and its associated materials provide the "pharmacopoeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of student accomplishments." Teachers should have vertical understanding of the curriculum of their discipline, as well as lateral understanding of what is taught in other disciplines for a particular level.

**Pedagogical content knowledge (PCK)**

Shulman (1986) describes pedagogical content knowledge (PCK) as a "blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction" (Shulman, 1987, p. 93). He argues that knowledge of subject matter alone does not make one a teacher. He further describes PCK as the kind of knowledge that "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986, p. 9). The difference between teachers and subject specialists is that teachers need to know the subject matter as well as how this content knowledge can be transformed into representations that are comprehensible to a group of learners with diverse interests and abilities (Shulman, 1987, p. 98).

**Knowledge of the learners**

This category of knowledge enables teachers to relate their teaching to the prior knowledge of learners, formulate representations that link with their interests and possess an understanding of their diverse abilities and ways of learning.
Knowledge of educational contexts
Shulman (1987) suggests that educational contexts range from "the workings of the group or classroom, the governance and financing of school districts, to the character and communities of culture." (p. 93).

Knowledge of educational ends, purposes, and values and their philosophical grounds.
This last knowledge category draws on the values and purposes of education that communities may have. It also acknowledges the effect of the historical background of the school or learning.

These are the categories of knowledge that Shulman considers as minimum requirements for teachers. However, he considers PCK as the most enabling. In describing PCK he hints at another type of knowledge — subject matter knowledge for teaching. He distinguishes this knowledge from PCK as concerned with the aspects of content that are most germane to its teachability (Shulman, 1986, p. 9). However, Shulman appears not to have perceived this kind of knowledge as a stand-alone domain in the teacher's knowledge base, as it is excluded in his list of knowledge categories. He did not define it as PCK but referred to it as reflecting knowledge linked to SMK with respect to its teachability. Unfortunately, his discussion on subject matter knowledge for teaching provided no examples of the components of such knowledge. On the other hand, Geddis and Wood (1997), argue that as a consequence of focusing on teaching as transformation of subject matter knowledge, a variety of different kinds of knowledge from which subject matter transformation emerge is observed (p. 612). The different kinds of knowledge include:

- learners' prior knowledge, including the preconceptions about a topic
- effective teaching strategies
- alternative representation of the subject matter
- importance of the topic to the overall chemistry curriculum — curricular saliency
- what makes the topic easy or difficult to understand

While Geddis and Wood (1997) did not give an overall term or title to these different kinds of knowledge, the authors clearly distinguished between these and subject matter knowledge per se, while emphasising their pedagogical transformative effect on SMK. In mathematics, Ball and her colleagues (Ball et al., 2008; Ball, 1999; Ball & Bass, 2000, 2003a) have spearheaded the notion of knowledge for teaching mathematics through a collection of empirical studies where they analyzed the core activities of mathematics teaching of specific topics (e.g.
multiplication, fraction, and division). What surfaced from their analysis was the evidence that teaching may require a specialized form of pure subject matter. Ball’s argument for referring to such knowledge as specialized includes the fact that the knowledge demonstrated by teachers in explaining operations was beyond mere algorithms commonly known to all professions using mathematics. ‘..Specialized Content Knowledge (SCK), is the mathematical knowledge and skill unique to teaching’ Ball, D. L., Thames, M. H. & Phelps, G. (2008, p. 400). In contrast to Geddis and Wood’s assertion, SCK does not include knowledge of students or pedagogy. Her work in this line of thought has gone further in identifying what such knowledge in mathematics may contain:

- Error analysis. She argues that mathematicians often engage in such practices. Exercising this activity in class would be congruent with Lave’s theory of situated learning (Lave and Wenger, 1991).
- Mathematical reasoning. This requires teachers to choose strategic examples in their teaching.
- Mathematical Language. Teachers are to explicitly demonstrate their understanding of language specific to mathematics e.g. how the mathematical meaning of edge is different from the everyday reference to the edge of a table.
- Common students’ conceptions and misconceptions about particular mathematical content.
- Mathematical knowledge of the design of instruction. Teachers’ understanding of sequencing particular content for instruction, choosing which examples to start with and which examples to use to take students deeper into the content.
- Horizon knowledge (Ball, 1993). This is the awareness a teacher possesses of how mathematical topics are related over the span of mathematics included in the curriculum.

While education researchers like Shulman, Geddis and Ball refer to and locate the above kinds of knowledge differently, what they have in common is a set of various knowledge types that enables its transformation for purposes of teaching. This set of various knowledge types is however not PCK as its composition excludes subject matter knowledge per se, a central aspect to PCK. This set of various knowledge types is an amalgam - of different knowledge affecting teachability of SMK. It talks to deconstruction, re-structuring, sequencing and representing SMK with the purpose of accessibility by students in mind. I posit that the process of
deconstruction and re-structuring is repeated for each topic of SMK, as each teaching instruction has been argued as a transformation of the SMK being taught. Therefore each topic of SMK, needs the amalgam talking specifically to it and therefore transforming the topic pedagogically. I have termed this \( \textit{amalgam} \) Topic Specific Knowledge for Teaching. Good understanding of a specific topic of subject matter knowledge per se, will not transform it for understanding by learners. It is the understanding of the topic specific amalgam \( \textit{amalgam} \) that provides the needed tools for knowledge transformation. Perhaps it is the topic specific amalgam that makes PCK topic specific. Various researchers have reported the topic specific nature of PCK (van Driel et al., 1998) and also that it contains elements relevant for teaching different topics. In this sense it is also considered to be subject specific (Davis & Krajcik, 2005; Friedrichsen, et al., 2009). While Geddis and Wood, and Ball et al. have formulated the components of TSKfT differently as described above, there are, however, common elements making the formulations similar in some aspects. The similarities include some elements listed by Ball et al. as constituting SCK. These are: teaching strategies/instructions, curriculum saliency, sequencing of content for instruction and representations. There are also differences between the two formulations. The major difference is the fact that Geddis and Wood have included specific pedagogically related aspects, such as students’ prior knowledge and teaching strategies, yet Ball et al. argue that SCK is purely related to content knowledge technicalities without reference to knowledge about students. In this study I have drawn the composition of TSKfT based firstly on the common elements listed by all the above authors (see Table 4.1 below):

<table>
<thead>
<tr>
<th>Knowledge types from which SMK transformation emerges’ : Geddis &amp; Wood (1997)</th>
<th>‘Specialized Content Knowledge’: Ball et al. (2008)</th>
<th>Topic Specific Knowledge for Teaching</th>
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<tr>
<td>Learners’ prior knowledge</td>
<td>Error analysis.</td>
<td>Error Analysis</td>
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<td>Effective teaching strategies</td>
<td>Mathematical reasoning.</td>
<td>Learners’ prior knowledge</td>
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<td>Alternative representations</td>
<td>Mathematical Language.</td>
<td>Effective teaching strategies</td>
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<td>Curricular saliency</td>
<td>Conceptions and misconceptions</td>
<td>Alternative representations</td>
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<td>What makes the topic easy or difficult to understand</td>
<td>Design of instruction.</td>
<td>Curricular saliency</td>
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<td>Horizon knowledge (Ball, 1993).</td>
<td>What makes the topic easy or difficult to understand</td>
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<td>Powerful analogies and examples</td>
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</table>

The newly formulated model TSKfT includes knowledge of learners’ aspects such as learners’ prior knowledge and teaching strategies that are absent in the model by Ball et al. The
consideration for inclusion of student’s prior knowledge in TSKfT, is to align with Shulman’s (1986) view of SMK transformation for the purpose of benefiting the learners. Thus the formulation of TSKfT leans more towards Geddis and Wood’s model. It may also be noted that the latter was derived from SMK transformations activities with both mathematics and science teachers, while Ball et al. is based on the work of mathematics teachers only. However, this fact does not limit inferences to be extrapolated for the science field as it has been done here, with the inclusion of error analysis that is relevant for quantitative work in science. TSKfT is regarded as everything about PCK that is explicitly related to subject matter knowledge. The diagram below presents the location of TSKfT with respect to the knowledge domains of PCK and PCK itself. The illustration has been adapted from the PCK model by Rollnick et al. (2008). In this model, PCK emerges from the amalgam of student context, student knowledge, subject matter knowledge and pedagogical knowledge domains. All these domains are underpinned by the teachers’ beliefs. The main adaptation to the model is the inclusion of TSKfT, as a knowledge domain from which transformation of SMK emerges and is, therefore, a connecting link between SMK and PCK. The link of TSKfT to aspects of student knowledge such as prior knowledge is illustrated by a faint line as it is not considered to be transformed by TSKfT. However, aspects of it are part of the knowledge types that constitute TSKfT.

![Figure 4.1: Teacher Knowledge domains of PCK](image)

The pedagogical transformative effect of Topic Specific knowledge for Teaching is being investigated in this study. The findings will be of great value for understanding the important concept of knowledge transformation. In addition to understanding knowledge needed to
4.5 Reasoning about Teaching

Good teaching is not only about knowledge but also the capability to reason soundly about teaching. Sound reasoning by teachers requires both a process of thinking about what they are doing and an adequate base of facts, principles and experience from which to reason. Shulman (1987) presented a theoretical framework entitled Pedagogical Reasoning and Action. The framework was derived from an empirical study of expert teachers. It consists of aspects of reasoning, starting with Comprehension, followed by Transformation, Instruction, Reflection and finally a New Comprehension. Shulman is less explicit on how these components may interact mathematically; however, the framework offers an opportunity of analyzing the teaching process that gives particular prominence to the idea of transformation of subject matter. In this study I have adopted the sequential representation by Bishop and Denley (2007) in discussing this framework. However, I remain cautious that the reasoning process may lift two or more components that may even be out of sequence simultaneously. Nonetheless, the sequential nature provides a platform for the study to discuss and analyze each component, specifically the transformation component and its sub-categories as they are of interest to this study. The discussion below looks into each of the components, as outlined in detail in Rusznyak, 2008, p, 111 -115, extracted and adapted for this study:

Comprehension

Shulman suggests that before teachers can embark on the act of teaching (in which ideas are exchanged), they first become learners themselves, as an idea is grasped, probed, and comprehended by a teacher, who must turn it about in her mind, seeing many sides of it (Shulman, 1987, p. 99). Teachers should comprehend not only the content and texts they intend teaching, but also the purposes and goals of the discipline itself. During this process of comprehension, Shulman suggests that teachers would draw on their subject matter knowledge as well as their knowledge of educational goals, purposes, and values and the philosophical and historical grounds on which these goals are based (Shulman, 1986).
Transformation
According to Shulman, transformation requires a combination of processes, each of which employs a repertoire: These processes are: preparation that requires critical interpretation, representation of ideas in the form of new analogies, metaphors etc, instructional selection from an array of teaching methods, and adaptation of these representations and tailoring for a specific learner audience. These processes enable the teacher to move from personal comprehension to preparation for comprehension of the other. They result in a plan to present a lesson. I note with interest the reference to common elements by both the amalgam of Topic Specific Knowledge for Teaching (TSKfT), as discussed above, and the set of repertoires for transformation described below:

(a) Preparation
The process of preparation involves examining and critically interpreting materials of instruction in order to detect errors and restructure the material into a form that is suitable for teaching (Shulman, 1987b, p. 102). This draws on TSKfT.

(b) Representation
The process of representation involves deciding what multiple forms of analogies, metaphors, examples, demonstration, simulations and the like would best represent the ideas to learners (Shulman, 1987b, p. 103). This again requires the teacher to draw on TSKfT.

(c) Selection
The teacher draws on his or her repertoire of instructional modes to select an instructional form or strategy that would be appropriate in the teaching of the particular lesson. Shulman (1987b) suggests that such a repertoire could include not only the more conventional alternatives such as lecture, demonstration, recitation, or seatwork, but also a variety of forms of cooperative learning, reciprocal teaching, Socratic dialogue, discovery learning, projects methods, and learning outside the classroom setting (p. 103). In this case, the teacher is drawing on general pedagogical knowledge and TSKfT.

(d) Adaptation and tailoring
The final steps in transforming the content for teaching involve fitting the represented material to the characteristics of learners. In adapting the represented material to learners,
the teacher may consider “aspects of [learner] ability, gender, language, culture, motivations, or prior knowledge and skills” (Shulman, 1987b, p. 103). A teacher may further tailor the content to the characteristics of a particular learner, if tutoring an individual rather than a class (Shulman, 1987b, p. 103).

Looking at the descriptions of the repertoires making up transformation, there is an almost total overlap between these processes and the amalgam of knowledge described as Topic Specific Knowledge for Teaching - TSKfT. Both these constructs refer to

- the need for ordering and re-arrangement of learning, in consideration of what is too difficult or easy or repeated about the curriculum to achieve most understanding.
- the need for representations and analogies in consideration of accuracy and students
- selection of appropriate instructional strategies or alternative strategies
- adapting and tailoring of the represented knowledge so that it fits the characteristic of the students' either based on student prior knowledge or backgrounds and contexts.

These similarities further support the link between Topic Specific Knowledge for Teaching and Transformation of that knowledge derived from the literature review earlier.

Shulman’s framework on Pedagogical Reasoning continues to provide platforms for deliberations on stages following successful transformation of SMK. The next stage is the actual enactment of delivering the instruction.

**Instruction**

This refers to “observable forms of classroom teaching” in which the prospective plan is enacted (Shulman, 1987, p. 101). It includes classroom management as well as presentation of content, interaction with learners, and assigning of work. Shulman argues that behavioural aspects of teaching and use of modes of instruction are bound up with comprehension and transformation of understanding (p. 105).

**Evaluation**

During the process of evaluation, the teacher checks for learner understanding while teaching interactively. Shulman (1987) argues that for a teacher to comprehend what a learner understands requires a deep grasp of both the material taught and the process of learning (p.106).
Reflection
Shulman (1987) defines reflection as "the set of processes through which a professional learns from experience" by reviewing the lesson in relation to the purpose that the teaching intended to achieve (p.106). It takes place when a teacher "looks back at the teaching and learning that has occurred, and reconstructs, re-enacts, and/or recaptures the events, the emotions and the accomplishments" (Shulman, 1987b, p. 106).

New comprehension
Shulman (1987) suggests that as a result of thorough 'reasoned' teaching, the teacher comes to a "new comprehension" of the "purposes and of the subjects to be taught, and also of the [learners] and of processes of pedagogy themselves" (p.106).

The pedagogical reasoning and action framework provides a process of reasoning about teaching. It is a framework that offers guidance on what to do with all the learnt different knowledge domains that comprise the epistemological structure of PCK. The framework enables one to reason about subject matter knowledge; knowledge about teaching the specific subject matter which has transformative effects; the actual action of good teaching and the following act of reflection about the delivered teaching. The framework offers a mechanism to accomplish the powerful statement by Shulman, that is, "... those who understand, teach" (Shulman, 1986, p. 14). I bring to the study an opportunity to investigate: (i) the impact of the exposure by pre-service teachers to the subject matter knowledge per se, (ii) its transformation for teaching purposes and (iii) the reasoning about its teaching. I argue that fostering all these three elements brings pre-service teachers closer to the implicit thoughts that expert teachers engage in. Thus, explicit exposure to such deliberations will, in a reciprocal way, enable pre-service teachers to learn how to teach their prospective students with the same benefits derived from rich PCK. I therefore define rich PCK in this study, as a function of transformation of SMK and pedagogical reasoning about teaching, as follows:

PCK is considered rich when for a given topic, there is evidence from pre-service teachers of pedagogical reasoning about their teaching prominent in the transformation of their comprehension as seen through the use of Topic Specific knowledge for Teaching in planning and delivery of actual lessons.
5. **THEORETICAL FRAMEWORK**

The theoretical framework proposed for this study, draws on two theoretical ideas, namely, the Pedagogical Reasoning (PR) model with its prominence in the concept of pedagogical transformation; and the Pedagogical Content Knowledge (PCK) model that gives prominence to Topic Specific Knowledge for Teaching. The PR model provides the reasoning process about teaching, while the PCK model provides the knowledge aspects of teaching. Both these theoretical ideas have been discussed individually in detail previously. The focus of this discussion is now placed on the inter-links that these ideas offer. The starting point of the PR process is the 'comprehension' of Subject Matter Knowledge. Comprehension, as subject matter knowledge per se, also enjoys a central role within the amalgam of teacher knowledge domains from which PCK is derived (Shulman, 1987). The positioning of 'comprehension' as a starting point in the PR model is equated to the emphasis of centrality of subject matter knowledge in PCK. The resulting inter-link is highlighted by the arrow line in the diagram below.

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**Figure 2:** Pedagogical Reasoning and Action model linked to PCK (TSKfT) Model
The next platform in the PR model is ‘Transformation’. This is the crux of the framework. Pedagogical transformation of SMK, reflected by the PR process, has been argued in the literature review to emerge from an amalgam of knowledge related to SMK that I have termed Topic Specific Knowledge for Teaching (TSKfT). TSKfT is a knowledge domain reflected in the PCK model. It is regarded as the connecting link between SMK and PCK. This link is argued in this study to be transformative; hence I have linked it to the repertoire of transformation steps of the PR process on the left.

The next stages of the PR model talks to the actual instruction and the evaluation and reflection that a teacher does. These stages are linked to the other knowledge domains of PCK that draw on knowledge of students, contexts, pedagogical knowledge and beliefs. According to Shulman (1987), on completion of the Pedagogical Reasoning process, teachers have developed new comprehension for their learners and for themselves. The merging of the two theoretical ideas displays a synergic fit, supporting the discussions about PCK, SMK and its transformation. On the basis of the displayed inter-links that reflect the equivalence of the respective components of the PR-PCK framework, it is therefore reasonable to interpret the evidence for the presence of Pedagogical Reasoning with its prominence in transformation as the presence of PCK. The extent of the quality of PCK may also be linked to the extent of evidence of Pedagogical Reasoning with subject matter comprehension and its pedagogical transformation being central. In this study, the PR-PCK theoretical framework will be used to inform the research design and the analysis of collected data on the learning and teaching aspects of Chemical Equilibrium. Chemical Equilibrium is one of the big ideas topics in chemistry perceived to be difficult to learn, but essential for understanding of other related topics. As such, research findings about aspects of its teaching are discussed in the next Section.

6. TEACHING AND LEARNING ASPECTS IN CHEMICAL EQUILIBRIUM

Research studies suggest that the understanding of chemical equilibrium is crucial as it constitutes the basic understanding needed in other chemistry areas such as oxidation-reduction and solubility (Begquist and Heikkinen, 1990). However, the topic is perceived to be difficult (Tyson and Treagust, 1999). Previously identified misconceptions continue to be detected despite recommendations available in the literature to correct these. Reasons given include the realization that the content of chemical equilibrium is abstract and the required explanations are
content and terminology specific (Ben-Zvi, Eylon and Silberstein J, 1988). Driver (1989) argues that it is not enough to simply alert students to the common errors as their ideas remain resistant to change, but properties of a science content should be linked to its teaching strategy (White, 1994). While the thrust of this paper is not on alternative conceptions that students hold about chemical equilibrium, it does form an important component of the amalgam of knowledge types that constitute Topic Specific Knowledge for Teaching (TSKfT), together with other learning difficulties and teaching strategies. Therefore the discussion below has relevance.

### 6.1 The Difficulty of Learning and Teaching Chemical Equilibrium

Tyson and Treagust (1999) warn that teachers tend to overlook the specific nature of chemical equilibrium and oversimplify their interpretations of certain concepts. The authors illustrate a subtle error made by teachers when introducing the topic of equilibrium by using an example of a physical system and expect extrapolation and accurate inference to be made to a chemical equilibrium system. They point out that in cases where teachers use the example of the reversible, physical system of dissolution such as that of sodium chloride, to introduce the concept of equilibrium; they tend to overlook the details. At a given temperature, there is a point where the solid sodium chloride added to the solution will not dissolve anymore and the maximum concentration of sodium ions and chloride ions in solution is reached. This point is called the saturation point. At this point in a physical system, equilibrium is reached. The addition of more solid sodium chloride will not affect the overall composition of the equilibrium mixture. It is suggested that students can understand this phenomenon with ease. The challenge surfaces when chemical equilibrium systems are discussed. The addition of a solid at equilibrium in a chemical system will also have no macro effect on the equilibrium, but for a different reason. For chemical equilibrium systems there is no point of saturation at any temperature. The lack of effect of a solid on equilibrium is because there is no consideration of liquids or solids in the expression for the equilibrium constant, $K_c$ only concentrations of components in the gas phase are considered. The pressure of the solid in the gas phase, and hence its concentration, is constant and its value incorporated into the value of the equilibrium constant. Often when students are asked for explanation of this observation, they erroneously bring across the similar interpretation as for physical equilibrium systems. It is suggested that the reason for this observation is partly because they were introduced to the concept of
equilibrium using examples that evidently go to completion first and struggle with the concept of incomplete reactions.

6.1.1 Limitations of Alternative Conceptual Explanations

It is further reported that students experience difficulty in predicting the effect of change when chemical equilibrium is disturbed (Hackling and Garnet, 1985; Voska and Heikinen, 2000; Kousathana & Tsaparlis, 2002). Three alternative conceptual explanations may be used independently to explain changes when equilibrium is disturbed. These are: the Le Châtelier Principle, Equilibrium Law and the Collision theory (Rates of Reaction). However each of these has subtle considerations that relate to the specificity of the type of equilibrium and reaction conditions in question. For example, according to the Le Châtelier Principle, the equilibrium system will oppose the change made to it. This principle will not hold when additional solids or solvents are added. Despite the fact that this is one of the widely reported limitations of the Le Châtelier Principle in the education literature, school and tertiary textbooks do not include this limitation. This results in the teaching of the Law without the discussions of its limitations. As a result it is often misapplied by students predicting the behaviour of an equilibrium system where the mass of solids is changed (Quílez-Pardo, 1995).

The next alternative explanatory theory is the collision theory. According to this theory, the existence of chemical reaction and its rate are a result of the physical contact of the reacting atoms. The theory does state that the amount of a solid will not influence the rate of chemical reaction, but particle size will. It is reported that the use of the phrase particle size creates potential misconceptions with reference to a meaning at macro vs. micro level. Students expressed confusion whether collision theory about rate of reaction will hold when powdered vs. pelletized form of solids are used (Tyson and Treagust, 1999). However, when choosing to use the Equilibrium Law, which has an equation that relates the concentrations of gaseous or aqueous reactants and products, at equilibrium at a given temperature, the potential confusion about the effect of solids at equilibrium may be avoided. The equation explicitly excludes solids. When students are able to link the equation to an actual reaction situation, they may find it plausible that solids do not affect the equilibrium.

6.1.2 Alternative Conceptions of specific content phrases

The meaning of specific terms used in chemical equilibrium has been found to have different meanings by students. In addition to the term particle discussed above, the very phrase equilibrium has been reported to have different meanings for students (Begquist and
Heikkinen, 1990). The commonly held alternative meaning is that ‘concentrations of all species (reactants and products) of a reaction mixture are equal at equilibrium’ (Tyson and Treagust, 1999, pg. 557). The other phrase reported challenging was the meaning of the phrase ‘equilibrium position’. Reported meanings by students include the same meaning as the phrase ‘equilibrium’ reference to the rate of reaction and a delay in reaching equilibrium. Further, difficulties are reported for: failure to distinguish between rate of reaction and extent of reaction (Banerjee and Power, 1991), the constant nature of the equilibrium constant, left and right sidedness (Kousathana and Tsaparlis, 2002) and mass vs. concentration (Wheeler and Kass, 1978).

While this discussion on chemical equilibrium difficulties is not exhaustive, it however, brings to the fore the importance of knowing what makes the topic difficult. It further highlights the common misconceptions that students hold. It provides insight into the limitations that different conceptual explanations (principles and theories) have when used in certain contexts. In a way, the discussion has begun the process of reasoning about teaching. It has brought to the fore considerations about the hard core content that must be made for effective teaching. These considerations have transformative effects on the content. Furthermore, the discussion on these considerations influences the teaching strategies that a teacher may choose. By ‘teaching strategies’ I place emphasis on the choices of examples used, warnings and discussions the teacher strategically chooses to discuss explicitly in class and those strategically avoided. The discussion below looks at recommended teaching strategies that are effective in relation to the specific difficulties of the discussed topic.

6.2 Recommended Teaching Strategies

Wheeler and Kass (1978) recommended the use of concentration vs. time graphs to assist students to visualize what happens as equilibrium is reached and when it is disturbed. This suggestion supports the point that was made much earlier by Hackling and Garnett (1986), i.e. to use quantitative aspects such as concentration to illustrate the relationships between species at equilibrium. Jordaan (1993) suggested the emphasis on ‘concentration’ and ‘temperature’ as the only two factors for which a disturbance of equilibrium may be explained using Le Châtelier Principle. Tyson and Treagust (1999) warn about the language used. Although certain terms are specific to the topic, the authors recommend that these phrases be avoided and/or re-phrased to avoid ambiguity at the introductory stages of the topic. For
example, the authors suggest avoidance of the term ‘equilibrium position’ and encourage rephrasing of questions or statements about this concept to refer to the concentrations of the species in equilibrium like ‘What happens to the concentration of a particular species in the equilibrium mixture?’ (pg. 558). Bilgin (2006), recommends that the small group work approach be used when teaching chemical equilibrium. His recommendation is based on the improvement in performance noticed when pre-service teachers were taught in small groups, creating opportunities to discuss both their misconceptions and new ideas. Quílez-Pardo (1995) warns that teachers should teach concepts in Chemical equilibrium with teaching strategies that are conceptually more exacting, and promote problem solving competencies. The use of rote learning and continuous use of algorithms do not develop the problem solving capacity demanded by the topic. These recommendations as well as the identified difficulties will influence greatly the planning and the delivery of the intervention on chemical equilibrium in this study.

7. RESEARCH QUESTIONS

The starting point of this study is the hypothesis based on Shulman’s (1986, pg. 9) theoretical idea paraphrased for pre-service teachers as follows: ‘For PCK to be developed in a pre-service programme, student teachers need not only develop understanding of SMK, but also develop the capability to transform it into various teachable representations and thoughtful explanations that learners can understand. Furthermore, pre-service teachers need to develop the ability to reason pedagogically about their teaching’. It is in the pedagogical reasoning that the evidence of blending different types of knowledge, and therefore PCK is observed. While the main focus of this study is on the development of PCK of pre-service teachers, it also acknowledges the influence of beliefs on teaching. It starts from the position that pre-service teachers need to be conscious of their own beliefs at first. Secondly, they need to be informed of those belief orientations that would support their teaching of science in a manner that reflects integrated understanding and, therefore, rich PCK. Such beliefs include the realization that teaching involves transformation of subject matter knowledge as pointed out by Geddis et al. (1993). The newly conceptualized idea of Topic Specific Knowledge for Teaching (TSKfT) as a set of knowledge types that provides teachers with the capability to realize transformation of their subject matter knowledge is thus evaluated. As Wilson and Berne (1999) said about 10 years
 ago: “the ‘what’ of teacher learning needs to be identified, conceptualized, and assessed” (p. 203).

With reference to the above, the main research question has thus been formulated as follows:
How and to what extent are the development of PCK of pre-service teachers and their beliefs influenced by the explicit inclusion of topic specific knowledge for teaching (TSKfT) when topics on chemical equilibrium are taught?
This research question has the following sub-questions
   i. What influence does the inclusion of TSKfT in teaching have on the understanding of subject matter knowledge, specifically Chemical Equilibrium concepts in this case?
   ii. To what extent does the explicit inclusion of TSKfT influence the development of pedagogical reasoning, and therefore PCK of pre-service teachers?
   iii. What influence does the intervention described in ii have on the initial beliefs held by pre-service teachers?
   iv. What tool would be suitable for measuring both the presence and the quality of pedagogical reasoning, and therefore PCK, displayed by pre-service teachers?

8. RESEARCH DESIGN

Mixed Methods

The research design is based on mixed-methods research (MM). MM is a less established research method compared to qualitative or quantitative methods as it has explicitly emerged as a standalone method only in the last few years. The philosophical orientation associated with MM is within the pragmatist paradigm, employing both narrative (qualitative) and numeric (quantitative) approaches to answering research questions (Teddie & Tashakkori; 2009). According to Fielding (2010), researchers are shifting focus to what is more practical and best to answer questions. Moran-Ellis et al. (2006) define mixed methods as the use of two or more methods that draw on different meta-theoretical assumptions (i.e. that are cross-paradigmatic). Mixed-methods studies can include standard positivistic quantitative and interpretive-qualitative components, or a mix of different qualitative data (positivistic, interpretive, phenomenological, visual) (p. 46). Bryman (2006) cautions that research studies often refer to the use of such approach without a rationale for why this was necessary or better than a mono-method approach. Others who did offer a rationale did not actually employ mixed methods in the study itself, while a third group offered a rationale and did administer mixed methods but relied on a single method for analysis of observations. He therefore emphasizes
the need for a rationale that is followed through from the beginning to the end of a study. That is, MM approaches should be linked to the research questions as well as the corresponding analysis. In acknowledgement of Bryman’s call, the rationale for the use of MM in this study is herein discussed: In recent times, mixed methods have been actively promoted, particularly in relation to research concerning social problems and the evaluation of social intervention programmes (Greene et al., 2001). The training and development of future teachers is regarded as a social activity; thus the method has relevance to the context of the study. Some of the benefits reported for using mixed methods include: (i) the accuracy of research findings and the level of confidence in them (Kelle, 2001); (ii) generating new knowledge through a synthesis of the findings from different approaches (Foss and Ellefsen, 2002); (iii) hearing different voices and bringing into play multiple constructions of the phenomenon (Moran and Butler, 2001); and (iv) reflecting the complexity of a phenomenon (Boaler, 1997). The use of the MM in this study is the enabling benefit of reflecting the complexity and the multifaceted nature of the interplay of the factors that influence the development of PCK in pre-service teachers. For example, the process of learning to reason pedagogically as pre-service teachers attempt to transform their SMK for teaching practice is a complex one. The process includes trial and error, making choices, adapting them and reflecting on them. Furthermore, the manifestations of their internal deliberation are seen through classroom discussions, suggested classroom lesson plans and enactment of teaching instructions. In an effort to reflect this constructive process as it unfolds from both verbal and written interactions, narrative qualitative method strategies will be best in capturing and analyzing the events. However, in order to develop an understanding of the extent of reasoning developed through the learning process, statistical quantitative methods on the same data will be more enabling. Similarly, for the research question on beliefs, establishing what beliefs are initially held by pre-service teachers is best reflected through descriptive qualitative method strategies. Yet the reflection of shifts in the beliefs as a result of the intervention is best captured statistically through quantitative strategies. Both these examples are different aspects of the same research sub-question, best answered by analyzing and integrating the findings of the different classical methods. On the other hand, other research sub-questions are answered best by the use of the mono-type research method. Questions with regard to validity of instruments used and the measurement of the significance of the shifts in test scores for SMK evaluations are best dealt with by quantitative methods. The interpretation of the findings for each sub-question, using and observing the validity aspects of the different research methods, will culminate in fruitful answers to the research question, and provide a response to issues of inference quality (Teddli
Punch (2005) identifies three key points for consideration when using mixed methods: whether the methods are taken as equal; whether or not they influence the operationalization of each other; and whether they are conducted simultaneously or sequentially. Moran-Ellis et al. (2006) argue that using mixed methods in an integrative manner requires that different methods (or types of data) are given equal weight, and, with respect to operationalization, that they are orientated to a common goal or research question and are, therefore, necessarily interdependent while retaining their paradigmatic modalities. In this study, both methods have equal weight as each captures a different aspect of the same question not reflected by the other. This ensures the required integration in MM. Furthermore, none of the methods follows a chronological order with one strand emerging from, or following the other. The design, therefore, meets not only the requirement for a rationale that flows through but also the criteria for a parallel mixed design. In this kind of the MM design, the qualitative and the quantitative strands of the study occur in a parallel manner either simultaneously as in this study, or with a time lapse, while answering related aspects of the same research question (Teddie and Tashakori; 2009).

8.1 Research Strategy: Case Study

The research strategy will take the form of a case study. The choice is based on the advantages that this approach traditionally offers. One such advantage is that it encourages the use of the MM research method, enabling targeted in-depth explorations of interactions. Also, in view of the complex and tacit nature of the theoretical concept of PCK, this approach will enable concentration on one or more instances to deal with the subtleties and intricacies of the construct. Merriam (2002, p. 8) describes a case study as "an intensive description and analysis of a social unit." The social unit in this study is a class of fourth year pre-service teachers. These are pre-service teachers in their final year of study towards a teacher qualification - the B Ed degree, with Physical Science as their major subject. Over the years the finalist class has had added to them, a few (about 2-3) students who have registered for a different qualification called the Post Graduate Certificate in Education (PGCE). The PGCE qualification is a one (1) year programme designed to provide the teaching and learning aspects of teaching science to students who are graduates of first degrees in traditional science qualifications. These students now wish to pursue teaching physical science as an alternative career. The presence of PGCE students in the final class of the B Ed degree is not guaranteed; it varies from year to year. However, together as a class of finalists working towards a similar
goal, they comprise a ‘social unit’. A case study is also regarded as a ‘bounded system’. It may be bounded by time and/or place (Babbie, 1992). The selected class meets this requirement. The class is bounded by the requirements of the qualification - studying a particular degree (BEd), and in the case of the added students doing PGCE, at a particular teacher education institution (Wits School of Education), for a specific time - four years for the majority (for which 2011 is the final year), and 1 year for the PGCE students. These boundaries are firm, unlikely to change during the term of the study as they have been defined in compliance of the qualification rules of the education institution, which in turn comply with the South African Qualification Framework. The selection of the class was based on the maturity of the pre-service teachers with regard to exposure to school teaching practice and a better grasp of science conceptual understanding. While the advantages for the use of a case study approach have been alluded to above, the limitations of the approach are acknowledged. One of the disadvantages of using a case study approach includes the limited extent of generalization of findings. According to Adler (2002), researchers in teacher education need to be conscious of and aim for a balance between insights offered by in-depth studies of specific exemplars, and broad generalized patterns from large samples. A case study, as a research strategy has limitations in that it has focused on a particular group, exclusive to others, restricting the generalization of findings as Adler cautions. This limitation will be minimized by using the whole class as a sample (see discussion on sampling below) and also providing thick descriptions of the events (Teddlie and Tashakkori, 2009). Further disadvantages of a case study refer to the perception that this approach produces soft data. The design of this study minimizes these disadvantages through the use of the MM method that produces both narrative (soft) and numeric (hard) data for analysis. Although the use of MM is reported to hold excellent promise for transforming research in teacher learning (Day, Sammons, and Gu, 2008; Johnson and Onwuegbuzie, 2004), this approach does not circumvent the innate biases, explicit or implicit, coupled with data collecting methods for empirical measurements. The data collecting methods proposed for this study and the associated considerations are discussed below.

9. DATA COLLECTION

Desimone (2009) warned against automatic biases against certain traditional data collection methods and encouraged placement of emphasis on the quality of their design and administration, and on the basis of best practice. She warns that the appropriateness of the data
collecting methods for a given research question should be the focal point of criticism (pg. 192). This study falls within the context of the teacher professional development and therefore acknowledges Desimone’s call in applying best practice in the choice and administration of the data collecting instruments. Data will be collected at the different stages of the study using pencil and paper questionnaires and diagnostic tests, interviews, observations, student portfolio assignments and field notes. Furthermore, recording of the intervention will be done using a video, while reflective journals and researcher notes will provide a rich source from which thick descriptions of the intervention may be developed.

(i) Pencil and Paper Instruments
The traditional pencil and paper research instruments will largely be questionnaires and diagnostic tests. Questionnaires will be used for eliciting responses related to the research question on teacher beliefs. Diagnostic tests will be used as achievement tests linked to answering the research questions on the effect of the intervention on understanding of SMK (Chemical Equilibrium). The instruments, both questionnaires and diagnostic tests, will be self-administered in the classroom supervised by the researcher as pre and post tests. Pencil and paper traditional research instruments have over the years retained their simplicity and ease of use, as no sophisticated equipment is needed, nor is specialized prior experience required of participants. In terms of best practice, teacher pencil and paper instruments, specifically questionnaires that ask descriptive and behavioral questions about the professional development experiences have been shown to have good validity and reliability scores (Mayer, 1999). However, when administered in a social setting such as a classroom, it is reported that participants tend to provide more sought after information and pleasing behaviors owing to the presence of the researcher or the assistant (Cronk and West, 2002). On the other hand, the presence, specifically the supervision provided by the researcher during the administration of traditional instruments, has a benefit ensuring completion of the instrument. Research further shows that teachers, generally, over-report their implementation of professional development and other reforms (Cohen, 1990; Ross et al., 2003). To minimize the resulting bias, Desimone (2009) encourages the use of multiple data collection method for triangulation of aspects of the same research question, as well as to cross-pollinate the different methods with questions capturing aspects of different research questions. One further limitation of the traditional pencil and paper is the scoring of responses that are less objective. This limitation will be minimized by co-opting an independent co-researcher for the task of scoring responses from
the instruments. The latter will further be used as schedules to conduct follow-up face to face interviews.

(ii) Interviews
Interviews will be used to collect data as a follow-up to responses captured on the beliefs and achievement pre and post tests. Selected questions from the pencil and paper instruments will be extracted and used as interview schedules. All interviews will be audio recorded and conducted in the presence of a co-researcher to minimize the bias due to familiarity of the participants with the researcher.

(iii) Observations
Observation provides a guard against over-reporting (Hintze & Matthews, 2004). Properly conducted observation can provide comprehensive, objective measures of what occurs in professional development and resulting classroom instruction. Observations will be the main method of capturing and measuring the quality of PCK in a selected few pre-service teachers who will be delivering real classroom lessons (details provided in the sampling section below). A tool for capturing and measuring the quality of PCK, developed in response to Research Question iv, will be used in the observations. Hardcopies of lesson plans, class activities and notes made by pre-service teachers during their lessons will be collected. A video camera will also be used to record the practice lessons. Each lesson will be followed up by a video stimulated recall interview to enquire and confirm interpretations of observations. Using video has the benefit of offering rich data that capture the complexity of interactions (Stigler, Gallimore, & Hiebert, 2000). Furthermore, captured interactions may be re-played several times for analysis. There are, however, many challenges to address. These include aspects of privacy and confidentiality issues, and determining what aspects of teaching should be videotaped.

(iv) Student Portfolio Assignments
One of the standard requirements of the B Ed programme is a major project assignment – designing a module and teaching instructions on a major topic in chemistry. The project assignment, among other things, requires students to re-organize and sequence the major concepts (Big Ideas) of a topic and provide reasoned out teaching strategies and practices. The reasoning behind the proposed teaching strategies is provided through qualitative descriptions. Included in the portfolio will be the completion of the PCK tool, in the form of a pencil and
paper, that captures aspects of SMK, its transformation and the pedagogical reasoning about its teaching. Pre-service teachers are required to submit the assignment in the form of a portfolio and also make presentations in front of their peers outlining their thinking in building up their portfolio. For this study, pre-service teachers will be asked to build their portfolios on the chemical equilibrium topic. The portfolios from all students will be collected as part of rich data on reflecting possible PCK development. The presentations of the portfolios will also be video recorded.

10. THE DEVELOPMENT OF DATA COLLECTION TOOLS

10.1 The Development of a PCK Tool

While it is best practice to use existing research tools for the evaluation of a widely researched topic such as PCK, the literature largely contains tools that only report on and probe PCK, but do not measure the quality of its strength. While some of these tools have been used in studies that include trainee chemistry teachers, similar to this study, the emphasis of measurement has been placed on selected categories of Shulman’s teacher knowledge identified as comprising PCK, namely student learning and instructional strategies. An example of such a tool includes the rubric developed by Lee et al. (2005). The tool is generic in nature, making it less appropriate for the topic relatedness of this study. Other tools reported in the literature are of a “probe” type with descriptive prompts for investigating PCK. Teachers are exposed to the probe, then respond either through pencil and paper data collection methods or interviews to reveal the PCK they perceived with respect to the material. However, these also emphasize selected categories of Shulman’s teacher knowledge that exclude TSKfT. An example of a probe-type instrument is that for mathematics by Krauss et al. (2008), with PCK categories for only subject matter knowledge, learner difficulties and pedagogical content. The tool is for mathematics education and in German. Another widely used instrument is the CoRe and PaP-eR devised by Loughran et al. (2004). The instrument has made a noticeable effort to address a range of knowledge types related to PCK. It is used to record teachers’ PCK and making it explicit. A CoRe provides a framework for tabulating the major SMK concepts of a topic referred to as “big ideas”. Big Ideas are planned-for and taught against prompts such as: intended learning about each big idea; the importance of learning the listed intentions; knowledge related to the Big Idea that the teacher holds back; possible difficulties with each Big Idea; related teaching strategies and assessment of intended learning. A PaP-eR provides a narrative account for each big idea in a CoRe, in the teacher’s voice. The PaP-eR highlights the
teacher's SMK, reflecting how teaching is intended, even including reflections on delivered lessons. The valuable contribution that the CoRe and PaP-eR instrument has made in opening an avenue for eliciting PCK among the education research community is acknowledged. In addition to organizing the SMK for a given topic, the CoRe and PaP-eR have evidence of considerations of those knowledge types that have a transformative effect on the SMK, such as curriculum saliency and consideration of commonly known difficulties for teaching a topic. However, these knowledge types are presented as standalone prompts with no clear relationship between them or explicit collective or common goals. Furthermore, the prompt on teaching strategies is often relegated to pedagogical methodologies missing out on the value of thoughts on powerful analogies, alternative representations and explanations. I therefore, argue that the CoRe and PaP-er instrument is good for qualitative rather than quantitative work as required in this study. A major consideration which brought about the posit of the theoretical idea of 'Topic Specific Knowledge for Teaching' in this study, is that none of the tools, including the CoRe and the PaP-eR, has placed emphasis on all of the following: (i) SMK, (ii) its Topic Specific Knowledge for Teaching from which transformation emerges and (iii) pedagogical reasoning about its teaching. The development of a tool that both elicits PCK and measures the quality of its strength with reference to the interplay of the above mentioned three constructs, will be the major contribution of this study to the body of science education knowledge and research on PCK. It is envisaged that the design structure of the tool, in alignment to the theoretical framework in this study, will respond to:

- an epistemological nature of PCK that includes TSKfT as a transforming agent connecting SMK to PCK
- the links connecting PCK and the Pedagogical Reasoning process
- a graded scale reflecting the quality of the observed PCK

Desimone (2009), recommends that, given the influence of teacher beliefs on learning and development, tools measuring impact on teacher professional development should include question items eliciting teacher beliefs, and that the responses be analysed in the context of the captured beliefs. While this study has a separate stand-alone research question on beliefs, and a dedicated research tool to elicit these, the recommendation for the inclusion of similar questions in the PCK tool will be implemented. Such cross pollination will also assist with issues of triangulation in establishing validity of findings. The unique feature of this tool will be the emphasis on topic specificity, which in turn may be applied to any given topic. The development process will begin with a scan of literature for existing PCK eliciting and
measuring tools including the CoRe and PaP-eR tool. The development process will explore both the qualitative features and the grading scale to measure the strength of the captured PCK. According to Loughran et. al, (2004) the process of developing a tool for capturing PCK requires working with teachers at both an individual and a collective level ‘….. PCK resides in the body of science teachers as a whole’ (pg. 374). It is therefore planned to form a working group comprised of science teachers as well as one or two independent science research educators who will participate in making input to the development process. The drafted tool will be piloted on a small group of volunteers, who are as similar as possible to the target population (see discussion on piloting below.)

10.2 The adaptation of the SMK performance tool on Chemical Equilibrium topics

Tools measuring for the conceptual understanding and for misconceptions on Chemical Equilibrium topics abound. Although the tools were used in different background contexts to this study, research studies indicate that widely identified misconceptions in Chemical Equilibrium are commonly held across many classrooms. For this research study, a two-tier conceptual test containing test items from Chemicals Equilibrium Achievement tests by Bilgin, I. (2006); Quilez-Pardo, J., Solaz-Portolez, J. J. (1995); College of Science (1997) will be used. Achievement tests by these researchers are widely referenced in empirical studies on learning and teaching Chemical Equilibrium topics. The Achievement Test, in the study, is comprised of 10-item multiple-choice questions. The test covers six aspects of chemical equilibrium:

- Mass vs. concentration — inability to differentiate between these concepts
- Rate vs. extent — how fast the reaction proceeds and how far it goes
- Constancy of the equilibrium constant
- Misuse of the Le Chatelier principle
- Constant concentration
- Competing Equilibria

The test yields two scores that reflect performance and misconception. The performance score is obtained when a student has keyed in a correct response in the chemical sense. A misconception score is obtained when an incorrect response is chosen in the chemical sense. Each question has a second stage for uncovering the understanding behind each choice of response made. Responses will be captured using the traditional pencil and paper method, where participants write on the test sheets. The benefit of such a two-tier test is that in
addition to one answer type of responses, qualitative insight into participants’ reasoning may also be established. Appropriate procedures for acknowledging the source of the test items have been followed. Internal consistency of the test was measured using the Cronbach alpha coefficient test. The Achievement test is attached as Appendix A.

10.3 The adaptation of the Tool on Beliefs

Similarly to availability of performance tools on Chemical Equilibrium, the literature has a number of empirical studies on beliefs of science teachers with various tools. Two studies with respect to teacher beliefs are of particular interest to this study. These are: (i) the development of a science teacher belief tool by Luft and Roehrig (2007) and (ii) the use of the tool with 114 beginning teachers by Luft (2009). The relevance is based on the similarity of the field of study (chemistry) and audience under study, namely, beginning teachers and the pre-service teachers in this study. However, the limitations resulting from differing contexts and cultures between the two countries are acknowledged. Nonetheless, the tool provides a base from which adaptation and modifications may be made for this study. The teacher belief tool from Luft and Roehrig is based on a qualitative research method. The authors used semi-structured interviews for collecting data, and code maps for scoring teacher responses. The authors report that they reviewed the tool several times to ensure elicitation of beliefs that are highly personal, and contained affective and evaluative components. The validity of the tool was tested through several interviews with different groups of teachers and by comparing their responses to that of the authors’ own questioning process. The authors report that

‘The language and explanations of the interviewed teachers indicated that they had created a non-threatening atmosphere in which genuine responses were possible. Our own verbal cues, along with the responses from the teachers, give us confidence in the reliability of the responses (Fowler, 1993). Finally, the Cronbach alpha coefficient for the internal consistencies survey was calculated at 0.70 (Luft and Roehrig, 2007, pg. 43).

The instrument is attached as Appendix B to this proposal. Modification of the tool for this study, in addition to language considerations, includes the addition of a question determining beliefs about the fact that teaching involves pedagogical transformation of the teachers’ subject matter knowledge.

10.4 Piloting Tools
All three tools on: PCK, Chemical Equilibrium Achievement test and Teacher Beliefs, will be piloted, respectively, on a small group of volunteers, who are as similar as possible to the target population (see discussion on sampling below.) Part of the investigation of the pilot will be to ask participants for feedback on ambiguities and difficult questions, the time taken to complete the test to establish whether it is reasonable and an assessment of whether each question yields an adequate range of responses. Depending on the findings, the tool will be revised and possibly piloted again. The internal consistency validity the tools will be established by measuring the Cronbach Alpha coefficient.

11. SAMPLING AND TREATMENT

The study will be located in a curriculum course of a class of fourth year pre-service teachers. These are pre-service teachers in their final year of study towards a teacher qualification - B Ed degree, with Physical Science as their major teaching subject. A large proportion of the B Ed students are from previously disadvantaged communities, and have come through the lower years of the B Ed qualification stream in the university (University of Witwatersrand). As explained in Section 8.1, over the years the finalist class has had added to them, a few (about 2-3) students who have registered for a one (1) year Post Graduate Certificate qualification in Education (PGCE), also taking Physical Science as their major teaching subject. The fourth year B Ed class, together with the addition of PGCE students, is typically a small sized class comprised of about 10 to 12 students. A similar pattern is expected for the fourth year class of 2011. The entire class will constitute the sample of the study and the unit of analysis will be the participants. The anticipated small size of the sample may pose a challenge in conducting quantitative research methods. However, it is proposed to explore quantitative methods that are applicable to small samples or administer the tool to a wider population to obtain baseline data.

The curriculum course traditionally deals with the methodology of teaching science concepts and is therefore appropriate for the kind of discussion and intended treatment emerging from the newly derived concept of Topic Specific Knowledge for Teaching. Prior to treatment, all three research tools will be administered as pre-tests that use the pencil and paper data collection method. The PCK and teacher belief tools will further be used as schedules in conducting pre-, semi-structured interviews that are captured through audio recording and researcher notes. The instruments will then be administered. The treatment will be the indirect introduction and development of PCK for a specific topic - chemical equilibrium in this case.
The introduction will be done through the explicit advancement of PCK building constructs. In this study, these are: (i) subject matter knowledge, (ii) its topic specific knowledge for teaching from which transformation emerges and (iii) the pedagogical reasoning about its teaching, all in a context embodying the underlying beliefs. The treatment will be organized into a total of 18 lessons carried out over six successive weeks. In each week there will be three lessons, each of which lasting about 50 minutes. All lessons will be video recorded for the purposes of developing thick descriptions of treatment. A record of daily events will be kept in a reflective journal. The treatment will have a learning and teaching resource package on chemical equilibrium and its teaching. The package will include various resource material in the form of notes, videos, class activities that in addition to SMK, addresses the prominence of PCK building constructs, including teacher beliefs. The following sequence and schedule is proposed:

Table 2: Sequence of the delivery of the treatment

<table>
<thead>
<tr>
<th>Week No.</th>
<th>No. of Periods</th>
<th>Equivalent Hours</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1.7</td>
<td>Teacher Beliefs on teaching and professional development</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.7</td>
<td>Teaching requiring transformation of SMK; and learning requiring construction of knowledge</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>4.2</td>
<td>Re-visitation of Chemical Equilibrium content</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>4.2</td>
<td>Topic Specific Knowledge for Teaching (TSKfT) as a tool for SMK transformation Chemical Equilibrium</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>2.5</td>
<td>Pedagogical Reasoning model as a tool for reasoning about teaching, using Chemical Equilibrium as an example</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>1.7</td>
<td>Pulling it together: Subject content on chemical equilibrium transformed for teaching using TSKfT and reasoning about its teaching.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 Tutorials</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20 hrs</td>
</tr>
</tbody>
</table>
The innovative element of the intervention will be, firstly, the explicit teaching of Topic Specific Knowledge for Teaching (TSKfT) on Chemical Equilibrium as the lessons unfold. Secondly, the Pedagogical Reasoning model will be introduced as a step-wise process for reasoning about preparing and teaching the topic. The most important part is the explicit demonstration of the link between TSKfT and the transformation of SMK for teaching purposes. Also, that aspect about transforming SMK and reasoning about its teaching may be captured and logged using instruments such as the CoRe & PaP-eR; concept maps and the PCK tool designed for this study. Lessons will have activity sheets with answer sheets where efforts with respect to SMK and SMK transformation using a template on TSKfT are recorded. Lesson activities will be extended to tutorial sessions providing further opportunities to practice reasoning about teaching using the Pedagogical Reasoning model, with interest in explicit reflection of the transformation stage. As mentioned in Section 9, one of the standard requirements of the BEd programme is a major project assignment, where pre-service teachers are required to design and present their reasoning for teaching a major topic in chemistry. The project presents an opportunity for pre-service teachers to display their SMK understanding, evidence of any pedagogical transformation of their SMK and reasoning on the actual delivery and evaluation of their proposed teaching. For this study, pre-service teachers will be asked to build their portfolios on the Chemical Equilibrium topic and present them in front of their class peers. All presentations of the portfolios in class will be video recorded to capture the narrative descriptions of the thinking behind each portfolio. On completion of the presentations, the Chemical Equilibrium conceptual understanding and the teacher belief tools will be re-administered as post-tests. A selection of a few pre-service teachers will carry out their portfolio plans into actual teaching of senior phase/FET learners in pre-arranged schools. Observations of the practice teaching lessons will be done through video recording and researcher notes. Video recall stimulated interviews will be conducted to collect further insights into the video recorded observations. These interviews will be audio recorded.

12. ANALYSIS

Each of the research tools will highlight both quantitative and qualitative aspects of the research question. With regard to PCK development, there will be various sources of the qualitative data collected. The qualitative responses captured from the pre and post testing will reflect PCK related to *in situ* processes of reasoning about teaching, while observations of
practice teaching through the video recordings, interviews and field notes will reflect PCK in action. As Boyatzis (1998) explained thematic analysis as a means of ‘seeing’ Observation precedes understanding (Pg.1). The qualitative data collected from the PCK tool will first be subjected to thematic analysis for identification of PCK (or lack of the same), then transformed for quantitative analysis to establish the quality of the strength of the observed PCK. It terms of thematic analysis, data sourced from written questionnaires and recording tools will first be transcribed, broken down and re-arranged following the unitizing and categorizing processes as refined by Lincoln and Guba (1985). This process will involve the continuous, repetitive coding and analysis comparing specific incidences in the data. The emerging patterns may also be compared to qualitative data about PCK from other sources such as the recorded pre and post interviews, presentations of the insight into the portfolios and other aspects of the portfolio. This process will be followed by the transformation of the data from qualitative to quantitative by scoring the answers. The services of an additional two independent researchers will be sought for co-scoring in order to increase the validity of the scores. The latter will be analyzed using appropriate statistical methods to detect shifts in the quality of the PCK strength. Since the PCK tools will have been pollinated with few questions on beliefs, the emerging PCK patterns will be interpreted with reference to the captured beliefs and any shifts in them, and also compared to the findings of the stand alone teacher belief tools. Data from the observations of practice teaching lessons through video recordings, will be transcribed and also subjected to thematic analysis. They will be combined with insights from the transcriptions of stimulated video recall interviews that were audio recorded. Findings from the practice teaching lessons will also be combined with those obtained from the PCK tools. Data from the teacher beliefs tools, captured through semi-structured interviews that were audio recorded and researcher notes on pencil and paper schedules, will first be transcribed. Three independent researchers will analyze them for scoring using code maps. Shifts between the pre and post tests will be established using statistical methods. Data collected from the two-tier conceptual understanding tool on Chemical Equilibrium topics, will be analysed using quantitative methods for the ‘answer’ component and qualitatively for narrative insights. Inferential statistics will be used to determine the effect of the intervention on performance. The scoring of correct answers from the SMK test will be one (1) point for the correct choice and zero (0) point for incorrect choices. Analysis of independent t-tests on mean and standard deviations of pre-post scores will be used to establish the presence of a significant difference between the pre-post tests. The narrative component of the tier test will be analyzed qualitatively for insight into the reasoning and alternative conceptions behind the answers. The benefit of using the
MM research method will be explored fully in these analyses, as each different set of analysis provides unique revelations and understandings about the research questions. The anticipated time framework for summarized preparation activities, data collection, treatment and analysis is as follows:
Table 3: Preparations towards data collection

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Activity</th>
<th>Research Strategy</th>
<th>Additional notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>October 2010</strong></td>
<td>Development of PCK tool and modification of conceptual understanding and teacher belief tools</td>
<td>Desktop literature reviews of existing PCK tools to inform development</td>
<td>Formation of teacher and researcher work groups - for reference and input.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modification of existing tools for performance and beliefs</td>
<td>Permission requests</td>
</tr>
<tr>
<td></td>
<td>Compilation of the Chemical Equilibrium Teaching Package with TSKfT</td>
<td></td>
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<tr>
<td><strong>November 2010</strong></td>
<td>Piloting of PCK, conceptual understanding and teacher belief tools</td>
<td>Advertisement of the project to volunteers in the current fourth year of study (class of 2010)</td>
<td>Benefit: a CD of electronic selective research papers on chemical equilibrium, PCK and beliefs related to beginning teachers</td>
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<tr>
<td></td>
<td>Updating research tools according to pilot findings</td>
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<tr>
<td></td>
<td>Re-piloting of updated tools if the need exists</td>
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<tr>
<td><strong>January 2011</strong></td>
<td>Conduct information session with the potential participants (class of 2011 fourth year) and request for consent permissions</td>
<td></td>
<td>Target induction period</td>
</tr>
<tr>
<td></td>
<td>Conduct similar information sessions with schools where relationships have been established</td>
<td></td>
<td>Copies of consent forms ready for distribution</td>
</tr>
<tr>
<td>Time frame</td>
<td>Activity</td>
<td>Research Tool</td>
<td>Data Collection Method</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------------</td>
<td>----------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>February 2011</td>
<td>Conducting Pre-tests</td>
<td>PCK, Chemical Equilibrium performance and Teacher Beliefs</td>
<td>Pencil and Paper self administered questionnaires for all three tools, and audio recorded, semi structured interviews for teacher beliefs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Additional source of qualitative data on PCK and teacher beliefs from interviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Quantitative analysis of performance scores and qualitative analysis of narrative components of the test</td>
</tr>
<tr>
<td>February – April 2011</td>
<td>Treatment over six weeks</td>
<td>Chemical Equilibrium resource package</td>
<td>Video recording of lessons and daily journals for purposes of thick descriptions.</td>
</tr>
<tr>
<td>April 2011</td>
<td>Post Testing</td>
<td>PCK, Chemical Equilibrium performance and Teacher Beliefs</td>
<td>Pencil and Paper self administered questionnaires for all three tools; Additional data sources for PCK include: end of programme portfolios, video recordings of portfolio presentations; video recordings of practice teaching of selected students, researcher observation notes, interview notes and audio records from video stimulated recalled interviews. Audio recorded post interviews for teacher beliefs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Additional source of qualitative data on PCK from class and tutorial activity sheets, submitted portfolios, recorded portfolio presentations, observations of practice teaching, audio recorded stimulated video recall interviews after practice lessons</td>
</tr>
<tr>
<td>May 2011 - 2012</td>
<td></td>
<td></td>
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</tbody>
</table>
13. VALIDITY AND TRUSTWORTHINESS

Data quality in MM research studies is determined by the separate standards of quality in qualitative and quantitative strands. According to Teddie and Tashakkori (2009), ‘if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality’ (pg. 209). As the research design for this study falls within the parallel mixed design category, the different standards for assessing the quality of data generated in the qualitative and quantitative strands will be discussed herein separately.

13.1 For the Quantitative Method

The quantitative method in the study is used for the measurement of Chemical Equilibrium performance scores and whether these scores differ significantly as a result of the intervention. The method is further used for measuring significant difference between quantitative scores of transformed data, reflecting the quality of the observed PCK, as well as teacher beliefs before and after the intervention. Traditional internal and external validity issues for quantitative studies will be observed. Internal validity will be established by controlling particular threats that might supply alternative explanations for studied outcomes (Onwuegbuzie, 2003). Strategies to minimize threats that may affect internal validity in this study include: establishing the content and correlation reliability of the instruments through consultation with subject experts during the designing and modification of instruments, as well as piloting the instruments of internal consistency and correlation as measured by the Cronbach’s alpha coefficient test. Furthermore, the inclusion of the entire class as a sample eliminates challenges associated with statistical regression and implementation bias associated with selective sampling. The use of co-researchers in interviews will minimize threats related to researcher and reactive biases by participants. External validity, on the other hand, reflects the degree to which study results could generalize to different places or persons. While the study may be limited by virtue of the nature of case study approach, it is envisaged that the inclusion of the entire sample provides maximum diversity possible in the given context. Also, the use of video recordings and daily reflective journals will assist to develop thick descriptions of the treatment, enabling repetitions and inferences to other similar contexts.
13.2 For the Qualitative Method

Trustworthiness is a concept introduced by Lincoln and Guba (1985) to represent many of the quality measurements in qualitative research. Trustworthiness for the qualitative strand of this study research will be improved through triangulation of different data sources, as will be the case with cross pollination of teacher belief questions into the PCK instrument. Furthermore, reliability of coding of participants responses from the pencil and paper instruments will initially be established through a training period, including two other co-researchers, consisting of multiple passes of sample responses in which consensus is built around interpreting and applying the methods, categories and their operational definitions. A reflective journal recording a variety of information on a daily basis will be kept to provide information on method and thoughts of the researcher. This enables thick qualitative descriptions of the study to be made. These in turn improve trustworthiness.

14. LIMITATIONS

In qualitative research, the researcher becomes the instrument for research (Fetterman, 1998, p 31). As the study will have a qualitative component, it will largely rely on my personal activities and outlook of the study. I intend to describe fully the methods followed and include interpretations of participants in the project to mitigate any bias or inadequacy. Although the research will be unable to claim generalizability because of its focus on a specific topic, (although a major topic in chemistry), it is expected to contribute substantially to the body of knowledge on the development of PCK, especially in pre-service teachers.

15. ETHICAL ISSUES

The study will be based on the principle of voluntary participation. This principle protects people from being coerced into participating in research. This is especially relevant in this study as the sample is a ‘captive audience’ in the specified academic programme. Working in close association with the principle of voluntary participation is the requirement of informed consent. For the study, an information session with the prospective research participants, the fourth year Physical Science class of 2011, will be conducted to fully inform them about the procedures, expectations and intentions of the study. Their consent to participate will be sought. Ethical standards also require that researchers not put participants in a situation where they might be at risk of harm as a result of their participation. Harm can be defined as both
physical and psychological. The study poses no physical harm to the participants as they remain in class as they would have in the absence of the study. For the psychological component, the principle of confidentiality will be applied in order to help protect the privacy of research participants. Pseudonyms will be assigned to protect identities. This also ensures that identifying information will not be made available to anyone who is not directly involved in the study. The study also involves learners in schools who will receive lessons as part of practice teaching by a selection of pre-service teachers in the study. Care will be taken that the learners are in a safe environment, typical of their familiar learning ethos. Permission will be sought from the participating institutions. Furthermore, the same principles of voluntary participation, informed participation and request for consent from relevant stakeholders (parents & guardians) and confidentiality will be observed. At the heart of this research is the recognition that education research with human subjects must benefit those who are involved in the study and that researchers have a responsibility to those who agree to be involved. Benefits will be realized only in future, but will also lead to improvements as the research is enacted (Tobin & Kincheloe, 2006). Pre-service teachers participating in this study will benefit from the exposure to a new concept on Topics Specific Knowledge for Teaching chemical equilibrium that has the potential to assist in fast tracking the development of their PCK, an attribute currently developed through teaching practice over years. Acquiring PCK at their stage of development will give them advantage and competence rarely found in beginning teachers.
REFERENCES


APPENDIX A: CHEMICAL EQUILIBRIUM ACHIEVEMENT TEST

**ACHIEVEMENT TEST:**

*Questions on Characteristics of a Chemical Equilibrium System*

1. Consider the reaction which is at equilibrium

   \[ C_2H_5NH_2 (aq) + H_2O (l) \rightleftharpoons C_2H_5NH_3^+ (aq) + OH^- (aq) \]

   Look carefully at the arrows and decide which of the following statements concerning the reaction at equilibrium is **CORRECT**.

   A. The reverse rate of reaction is lower than the forward rate of reaction.
   B. The forward rate of reaction is greater than the reverse rate of reaction
   C. The forward and reverse rates are equal.
   D. The concentration of products is higher than that of reactants.
   E. The concentration of reactants and products is the same.

   i. All Options
   ii. A, B and D only
   iii. C and D only
   iv. C and E only

   Explain your answer
2. For the reaction \[2\text{NO}(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{NOCl}(g)\]

which of the following is **FALSE** about the reaction when at equilibrium

A. the constant for the reaction is equal to concentrations of reactants divided by the concentrations of products.

B. the addition of a catalyst will drive the equilibrium in any desired direction

C. the rate of change of concentrations of reactants and products is constant.

D. the concentration of NO equals the concentration of NOCl.

i. A and B only  
ii. A and C only  
iii. B and D only  
iv. C and D only  
v. D only

**Explain your answer**

3. Look at the equilibrium reaction represented by the equation:

\[\text{N}_2\text{O}_4(g) \rightleftharpoons 2\text{NO}_2(g)\]

Which of the following statements concerning this reaction at equilibrium is **FALSE**?

A. The ratio of the concentration of \(\text{N}_2\text{O}_4(g)\) to the concentration of \(\text{NO}_2(g)\) is 1 to 2.

B. From the balanced equation, it is clear that 1 molecule of \(\text{N}_2\text{O}_4(g)\) produces 2 molecules of \(\text{NO}_2(g)\).

C. The equilibrium constant \(K_c\), is  
\[K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = \frac{2^2}{1} = 4\]

i. A only.  
ii. A and C only.  
iii. A, B and C  
iv. B only.  
v. A and B only.  
vi. B and C only.

**Explain your answer**

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4. Consider $\text{H}_2$ and $\text{I}_2$ molecules that undergo reaction by providing suitable conditions in a closed system to form hydrogen iodide and reach equilibrium.

$$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$$

Use representations such as a solid sphere to represent the hydrogen atom, and an empty spheres to represent the iodine atom; to draw

A. A representation of the system at the beginning of the reaction, when there is an equal numbers of Hydrogen and Iodine *molecules.
B. At equilibrium
C. 2hrs after reaching equilibrium

*Note that Hydrogen and Iodine exist as diatomic molecules, for example

the Hydrogen molecule may be presented as: ☺

while the Iodine molecule represented as: ☺
Questions on Misapplication of the Le Chatelier’s Principle

5. The reaction, \( \text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \)
is at equilibrium in an empty reaction vessel fitted with a movable piston.

5(a). What will happen if some argon (an inert gas) is added to the equilibrium mixture
at constant pressure and temperature?

A. More \( \text{PCl}_3(g) \) and \( \text{Cl}_2(g) \) will be formed.
B. The total pressure will increase instantaneously, \( \text{PCl}_3 \) molecules will combine with
\( \text{Cl}_2 \) thus more \( \text{PCl}_5(g) \) will be formed.
C. There will be no effect because argon does not react with any of the substances in
the equilibrium mixture.

Explain your answer
5(b). What will happen if the piston is pushed into the equilibrium mixture, reducing the total volume of the vessel?

A. More \( \text{PCl}_3(g) \) and \( \text{Cl}_2(g) \) will be formed.
B. The total pressure will increase and volume decreased, \( \text{PCl}_3 \) molecules will combine with \( \text{Cl}_2 \) thus more \( \text{PCl}_5(g) \) will be formed.
C. There will be no effect because no additional reactant or product was added.

6. The decomposition of ammonium chloride reaches equilibrium in a closed container at a given temperature

\[
\text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g)
\]

What will be the effect on the equilibrium mixture of the following changes (keeping the temperature constant)?

A. Addition of \( \text{NH}_4\text{Cl}(s) \)
B. Addition of \( \text{N}_2(g) \)

Notes: The flask is fully rigid and nitrogen does not react with any of the chemicals involved in the equilibrium

7. In a solution of acetic acid in water the following equilibrium is established:

\[
\text{CH}_3\text{CO}_2\text{H(aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{CH}_3\text{CO}_2^- \text{(aq)} + \text{H}_3\text{O}^+(\text{aq})
\]

To begin with we have 100 ml of a 1.0 M solution of acetic acid, and then enough water is added to obtain 1 L of a new solution:

A. Explain the possible effect of adding water to the equilibrium position.

Explain your answer
Disturbances to Chemical Equilibrium

8. The exothermic reaction \( \text{O}_2(g) \rightleftharpoons \text{O}_3(g) \) was allowed to come to equilibrium, as represented in the box below:

A. Some \( \text{O}_3 \) was added to the system at equilibrium. Which box (A – E) best represents the new position of equilibrium? Explain your answer.

B. The temperature of the system at equilibrium was increased. Which box (A – E) best represents the new position of equilibrium? Explain your answer.

C. The pressure of the system at equilibrium was increased. Which box (A – E) best represents the new position of equilibrium? Explain your answer.
References for the Test items


ACHIEVEMENT TEST: ANSWERS

Questions on Characteristics of a Chemical Equilibrium System

1. Option (i), C and D only

   Explain your answer
   The rates of forward and reverse reactions will be equal and, the longer arrow pointing towards products indicate that the reaction, at equilibrium, will have a greater concentration of product than reactant at equilibrium.

2. Option iii, B and D Only

   Explain your answer:
   Catalysts affect the speed of the reaction and have no effect on the equilibrium concentrations, and the direction of the reaction. The main effect of a catalyst is to speed up the time needed to reach equilibrium.

3. Option ii, A and C only.

   Explain your answer
   This question is exploring the idea that equilibrium concentrations are not necessarily related to the stoichiometry of the equation, but for every occurrence of the reactants turning into products, the stoichiometry must be observed. Thus the line indicating the changes in concentration is the one that obeys the stoichiometry of the equation.

4. Answer:

   \[ \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \]

   A. At the Beginning of the Reaction:
   Drawing: 
   Diatomic molecules of Hydrogen and Iodine gases at the beginning before reaction

   B. At Equilibrium:
   Drawing:
   The rate of forward reaction same as reverse reaction, similarly the proportions of concentration of products formed will be equal to the stoichiometrically allowed proportions of reactants

   C. 2 hrs after reaching Equilibrium:
   Drawing:
   If equilibrium not disturbed the representation of microscopic changes remains same as in equilibrium
5. (a) Option C, 

**Explain your answer**
Argon is an inert gas, not part of the reaction, therefore the equilibrium constant $K_c$ will remain unaffected, therefore to effect observed.

(b) Option B

**Explain your answer**
As the volume is decreasing, the gas molecules of the reactants have limited space, the number of molecules per volume unit increases, thereby increasing collision and therefore formation of the product as that reduces the number of gas molecules per given volume. The production of the reactants is favoured until a new equilibrium is reached.

6. 

\[ \text{NH}_4\text{Cl(s)} \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \]

**Explain your answer**
(a) The addition of a solid has no effect on the equilibrium since the concentration of a solid remains constant.
(b) The addition of Nitrogen gas has no effect on the equilibrium since it is inert and does not participate in the reaction

7. **Answer:**

\[ \text{CH}_3\text{CO}_2\text{H(aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{CH}_3\text{CO}_2^- (aq) + \text{H}_3\text{O}^+(aq) \]

(a) Explain the possible effect of adding water to the equilibrium position.

**Explain your answer**
Acetic acid is a weak acid, therefore its dissociation its limited. The addition of water will not dissociates more acetic acid, therefore the equilibrium will not be affected.
**Disturbances to Chemical Equilibrium**

8. The exothermic reaction \( \text{O}_2(g) \rightleftharpoons \text{O}_3(g) \) was allowed to come to equilibrium, as represented in the box below:

2. Some \( \text{O}_2 \) was added to the system at equilibrium. Which box (A–E) best represents the new position of equilibrium? Explain your answer.

   **Explain your answer**
   B is the only correct box. The original equilibrium system consisted of 6 \( \text{O}_2 \) and 4 \( \text{O}_3 \). If some \( \text{O}_2 \) are added to this system, some of the \( \text{O}_2 \) will react (equilibrium will shift to the left) and produce some \( \text{O}_3 \), until the ratio of \( \text{O}_2 \) to \( \text{O}_3 \) is once again the equilibrium ratio. Both boxes B and C have this ratio, but box B has additional \( \text{O}_2 \) and \( \text{O}_3 \), as required by the problem.

3. The temperature of the system at equilibrium was increased. Which box (A–E) best represents the new position of equilibrium? Explain your answer.

   **Explain your answer**
   E is the only correct box. The effect of increasing temperature on an exothermic reaction is to decrease the value of the equilibrium constant (equilibrium will shift to the left), decreasing the amount of product and increasing the amount of reactant. In box E the ratio of \( \text{O}_2 \) to \( \text{O}_3 \) has decreased from 6:4 (10 total) to 5:5 (10 total). In all other boxes the ratio is equal to or greater than the original ratio.

4. The pressure of the system at equilibrium was increased. Which box (A–E) best represents the new position of equilibrium? Explain your answer.

   **Explain your answer**
   C is the only correct box. Pressure should have no effect on the position of equilibrium, since there are the same number of gas molecules on both sides of the reaction. The original number of \( \text{O}_2 \) and \( \text{O}_3 \) should still be present.
APPENDIX B: TEACHER BELIEF TOOL - QUESTIONNAIRE:

1. How do you maximize student learning in your classroom? (learning)
2. How do you describe your role as a teacher? (knowledge)
3. How do you know when your students understand? (learning)
4. In the school setting, how do you decide what to teach and what not to teach? (knowledge)
5. How do you decide when to move on to a new topic in your classroom? (knowledge)
6. How do your students learn science best? (learning)
7. How do you know when learning is occurring in your classroom? (learning)

An example of categorizing captured beliefs is given below:

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
<th>View of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional: Focus on information, transmission, structure, or sources.</td>
<td>I am an all knowing sage. My role is to deliver information.</td>
<td>Science as rule or fact.</td>
</tr>
<tr>
<td>Instructive: Focus on providing experiences, teacher-focus, or teacher decision.</td>
<td>I want to maintain a student focus to minimize disruptions. I want to provide students with experiences in laboratory science (no elaboration).</td>
<td></td>
</tr>
<tr>
<td>Transitional: Focus on teacher/student relationships, subjective decisions, or affective response.</td>
<td>I want a good rapport with my students, so I do what they like in science. I am responsible to guide students in their development of understanding and process skills.</td>
<td>Science as consistent, connected and objective.</td>
</tr>
<tr>
<td>Responsive: Focus on collaboration, feedback, or knowledge development.</td>
<td>I want to set up my classroom so that students can take charge of their own learning.</td>
<td>Science as a dynamic structure in a social and cultural context.</td>
</tr>
<tr>
<td>Reform-based: Focus on mediating student knowledge or interactions.</td>
<td>My role is to provide students with experiences in science which allows me to understand their knowledge and how they are making sense of science. My instruction needs to be modified accordingly so that students understand key concepts in science.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C: Sample Letter Requesting Permission

Wits School of Education
27 St Andrews Road
Parktown
Date

Dear Student teacher

I am currently doing a research dissertation towards my PhD in Education degree, specialising in science teacher development. I am researching the development of Pedagogical Content Knowledge (PCK) in pre-service programme. PCK is the kind of knowledge that enables the teacher to transform her comprehension about subject matter in a manner that students understand, and subsequently record good performance. I am specifically interested in B. Ed student teachers, who are specializing in Physical Science, FET Phase, who are now in their fourth year of study. I believe that your input and experience would be a very valuable source of information for, and I would like to invite you to join the study.

This study, happens in the methodology class which is part of the curriculum component of your course. Therefore, you will need to participate in class as normal and work towards all activity and assignment requirements as they will be counting towards your performance as normally required. There will be an information session where all the details of the study are explained. You will be asked to participate in tests conducted prior to any teaching in the programme, that aim at eliciting your thoughts about the process of teaching and your beliefs about teaching and learning. These tests are pencil and paper type and last about 60 minutes. They will be follow-up by interview sessions also lasting about 60 minutes. The interviews will happen outside the teaching time at times pre-arranged with you. The discussion during the interviews will taped and transcribed for analysis. At all times, your name will be kept confidential i you will be identified by a pseudonym only. The people you may mention will also be kept confidential. You may be quoted in the dissertation, but it will be done in such as way that your identity is not revealed.

The purpose of this investigation is to identify those knowledge types and processes that will help graduating science teachers to conduct their early lessons with confidence and expertise that leads to improved understanding by learners. The dissertation will be published, and the research generated may lead to staff seminars. It is hoped that any input you share may help the university to modify the undergraduate teacher preparation programmes such that graduate teachers become beginning teachers full with confidence and teacher expertise. Furthermore, as a student teacher in your final year, exposure to the treatment will give you advantage in possibly improving your PCK in teaching Chemical Equilibrium. You will also have access to the research findings once published.

Yours sincerely
Ms Elizabeth Mavhunga
(Researcher)
Informed Consent form (adapted from: Rusznyak, L. (2008)).

Research Dissertation: PhD: The Relationship between explicit inclusion of Topic Specific Knowledge for Teaching and the Development of PCK in Pre-Service Science Teachers.

I, ________________________________ consent to participate in this study conducted by Elizabeth Madlivane Mavhunga (8511166) for a research dissertation investigating the development of PCK in science pre-service teachers.

I realize that no harm will come to me, and that the research is being conducted for educational purposes.

I participate voluntarily and that I may withdraw from the study at any time.

I also have the right to review the transcripts made of our conversation before these are used for analysis, if I so choose.

I can delete, amend or retract any of my remarks.

Everything I say will be kept confidential by the interviewer. I will only be identified by a pseudonym in the dissertation. In addition, any persons I refer to in an interview will be kept confidential.

Quotes from me may be used in the dissertation, but they will be reported in such a way that my identity is anonymous. Any specific individuals I refer to will be given a pseudonym. I understand that the dissertation will be published, but my identity will remain anonymous.

Name :_____________________________________

Signature:_____________________________________

Date :_______________________________________