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# Distinguishing Topic-Specific Professional Knowledge from Topic-Specific PCK: A Conceptual Framework

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**ABSTRACT**

The purpose of this conceptual paper is to present a review of the literature on pedagogical content knowledge (PCK) that explores and critically analyzes the conceptualization of topic-specific science PCK in the light of previous discussions and research on science PCK as well as the new developments. I investigated the literature on PCK that has contributed to the conceptualization of PCK since its introduction by Shulman (1986) to understand topic-specific pedagogical content knowledge (TSPCK) and distinguish it from topic-specific professional knowledge (TSPK). This paper provides a conceptual framework to further elaborate on the concept of TSPK by identifying TSPK components and presenting possible ways for these components to emerge or develop. This framework viewed TSPCK as a combination of knowledge and skills, where (1) knowledge is represented by the development of TSPCK components as a result of (a) interpretation, (b) integration, or (c) specification and skills are represented by (2) integration of TSPK components by individual teachers to help students understand a science topic.

**Keywords:** pedagogical content knowledge (PCK), science teachers' professional knowledge, Topic-Specific PCK (TSPCK), Topic-Specific Professional Knowledge (TSPCK)

## INTRODUCTION

The notion of pedagogical content knowledge (PCK) was conceived by Shulman (1986, 1987) who first introduced the idea of PCK in 1986 in his project, *Learning to Teach,* where he pointed to the importance of subject matter knowledge for understanding, studying, and developing teacher knowledge. Shulman (1987) considered PCK as the integration of content knowledge and pedagogical knowledge. According to him, PCK is an amalgam of various teacher knowledge categories, which includes "the most useful forms of content representation, . . . the most powerful analogies, illustrations, examples, explanations, and demonstrations, . . . the ways of representing and formulating the subject matter that makes it comprehensible for others" (Shulman, 1986, p. 9). He also asserted that teachers' knowledge of teaching centers on individual topics, referring to PCK as topic-specific knowledge.

The notion of PCK has evolved over the last three decades as a result of scholarly contributions by many researchers (for example, Gess-Newsome, 1998; Grossman, 1989; Hashweh, 1987; Lee & Luft, 2008; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Magnusson, Krajacik, & Borko, 1999; Mark, 1999; Park & Oliver, 2006; Tamir, 1988). After almost three decades, even after substantial research into science teacher knowledge, the notion of PCK introduced by Shulman (1986, 1987) has still not reached a clear, agreed-upon definition among researchers (Abell, 2007; Berry, Loughran, & van Driel, 2008). The PCK construct has been

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used inconsistently, and many of its aspects have been overlooked (Abell, 2007, 2008). According to Berry, Loughran and van Driel (2008), the construct has become so seductive for its potential usefulness in teacher education programs that research on PCK has mostly ignored careful clarification of the construct of PCK. Therefore, "the construct [PCK] did not impact the valuing of science teachers' professional knowledge and practice positively, which is a major concern for such an important profession" (p. 1272).

Research on science teachers' PCK has focused on (1) understanding the PCK construct and (2) studying or assessing science teachers' PCK of teaching various curriculum areas and topics. Research on the PCK construct covers several constituent parts included in PCK, referred to as teacher knowledge categories, such as content knowledge, knowledge of the curriculum, and knowledge of goals. It also covers the connections between these teacher knowledge categories representing the PCK construct as a conceptual framework or model (for example, Hashweh, 2005; Magnusson, Krajacik, & Borko, 1999; Park & Oliver, 2008) leading to varied conceptualizations of PCK. Moreover, in the body of research on the PCK construct, researchers have focused on varied curriculum topic areas and teachers' backgrounds, but they have not made a sufficient distinction between them. Conversely, the research on studying, assessing, and measuring has mainly focused on selected teacher knowledge categories of PCK to understand how science teachers develop or use these categories, to teach a specific science topic. This line of research gave rise to the idea of topic-specific science PCK, however, without considering a place between TSPCK within the broader PCK construct. This resulted in a widening of the gap between the two research areas.

Topic-specific nature of PCK had been a part of many discussions on science PCK (Kind, 2015; Loughran et al., 2001, 2004; Park & Oliver, 2008; van Driel, Verloop, & DeVos, 1998). Despite ample discussions, the PCK models had not explicitly focused on topic-specific PCK. The recent discussions on PCK have reinforced the topic-specific nature of science PCK, and some scholars in the area of science education proposed topic-specific PCK (TSPCK) models (Azam, 2015; Mavhunga, 2014; Muvhunga & Rollnick, 2011) and preferred to call their conceptualization specifically topic-specific PCK (TSPCK).

Recently, the Consensus Model (CM) of PCK developed as a result of PCK summit, considered PCK as a topic-specific knowledge within topic-specific professional knowledge (TSPK) (Gess-Newsome, 2015), however, it is not clear how these two are connected. Moreover, there is a need to unpack TSPK and TSPCK, so that a better understanding of science PCK is achieved. This conceptual paper is an effort to narrow the gap between the above two types of research on science PCK by suggesting a working model that will further continue the discussion on conceptualizing TSPCK and depict a connection between TSPCK and TSPK. The construct of PCK lacks clarity both structurally and philosophically. The nature of pedagogical content knowledge is less delineated. However, I will save that discussion for another time and keep the focus of this paper on structural aspects of PCK.

## METHODS

To include in this targetted review, the searches were conducted to find articles on PCK: (i) with the sole purpose of understanding PCK and provided visual frameworks, popularly called as PCK models and (ii) with the purpose to report research on science teachers' PCK. The beginning point of this search was set as 1986 when Shulman published his groundbreaking paper, Those Who Understand: Knowledge Growth in Teaching and coined the term pedagogical content knowledge along with a preliminary conceptualization of it. First, the articles that featured and illustrated PCK conceptualizations were critically reviewed to offer a synopsis of various conceptualizations of PCK; the purpose was to unpack the complexities and track the advancement of the PCK construct. Second, the articles reporting research on science teachers PCK were reviewed. After 2006, the research on science teachers' PCK expanded exponentially, therefore, search was focused on major science education journals, and I present the information from these articles organized **in Appendix A**, to examine the purposes of research, the theoretical frameworks/PCK models employed to frame these research studies, and PCK aspects studied. This review was targeted to compare the two sets of articles on PCK to investigate how they support each other and inform the conceptualization of topic-specific science PCK.

## FINDINGS

In the following sections, I present this targeted critical review of PCK literature. I begin this review with a section on the evolution of ideas about the construct PCK to discuss the structural features of the PCK construct and the developments leading to the expansion of this construct. Next, I describe theoretical underpinnings and the characteristics of the research on science teachers' PCK of teaching specific science topics to identify the gap between the two sets of articles, lack of connection between topic-specific professional knowledge (TSPK) and topic-specific PCK (TSPCK). I, then, propose a working model, a conceptual framework, which provides a heuristic to capture TSPK and TSPCK, followed by a conclusion and implications for using this conceptual framework to access and assess topic-specific professional knowledge of teaching science, which includes TSPCK.

## Evolution of Ideas about the Construct PCK

The notion of PCK as defined by Shulman (1986, 1987) and elaborated by many scholars (for example, Gess-Newsome, 1998; Grossman, 1989; Hashweh, 1987; Lee and Luft, 2008; Loughran et al., 2001; Magnusson et al., 1999; Mark, 1999; Park and Oliver, 2006; Kind, 2015; Tamir, 1988) has evolved over last three decades. When Shulman (1986) introduced the term "pedagogical content knowledge" he considered PCK as a subcategory of content knowledge, but soon after, He rejected this idea in his 1987 paper "Knowledge and Teaching: Foundation of the New Reform," and redefined PCK as a distinct teacher knowledge category, and defined it as "a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of understanding" (Shulman, 1987, p. 8). He reconsidered PCK as a "distinctive body of knowledge for teaching which represents the blending of content and pedagogy into an understanding of how particular topics, problems, and issues are organized, represented, and adapted to the diverse population of learners and presented for instruction" (Shulman, 1987, p. 8). He also asserted that teachers' knowledge of teaching centers on individual topics, referring to PCK as topic-specific knowledge. However, two confusions about PCK had been prevailing: (a) if PCK is topic-specific or generic knowledge and (b) if PCK is to be considered as a transformation of subject matter knowledge (Hashweh, 2005). After three decades of discussions, PCK has started attaining its topic-specific nature. Nevertheless, some of the research on PCK persists in using Shulman's initial view and definition of PCK as a type of content knowledge or transformation of content knowledge.

When Shulman conceptualized PCK in 1986, he referred only to the knowledge of students' understanding and instructional strategies (which he initially called representations) as the fundamental components of PCK. These two components of PCK have been of prime focus for research on science teachers' PCK, and a consensus has been reached for these two components to be a constituent part of science PCK (Berry, Loughran and van Driel, 2008. Subsequent research and discussion on PCK explored the teacher knowledge categories that shape the PCK of teachers in various curriculum areas, which led to including other teacher knowledge categories (components) in the definition of PCK (Grossman, 1989; Loughran et al., 2001; Magnusson et al., 1999; Tamir, 1988). Many researchers have raised questions about the conception and structure of PCK, and their critical contributions have introduced various expansions to the construct of PCK, including new knowledge categories. **Table 1** provides a summary of the research on development and understanding of the construct PCK, showing various knowledge categories considered to be included in PCK by different scholars. This analysis of research on PCK expansions over last three decades points to several issues: (1) Inconsistency of types of knowledge categories within PCK, and (2) Role of subject matter knowledge (SMK) within PCK while few kept it outside the construct. Despite a general disagreement on types of teacher knowledge categories included in PCK, an agreement has been archived for a few teacher knowledge categories included in PCK. These knowledge categories include knowledge of students' understanding and knowledge of instructional strategies (Abell, 2008; Berry, Loughran & van Driel 2008). Similarly, scholars in the area of PCK are divided on the role of SMK in PCK. However, content knowledge understanding has been considered useful for the development of science teachers' PCK (Abell, 2008; Kind, 2015). The researchers who considered content knowledge (CK) included in PCK (Hashweh, 2005; Loughran et al., 2001) have focused on the integration of various knowledge categories including CK, to become science teachers' PCK.

**Table 1.** Summary of Prominent Research on Development and Understanding of the Construct PCK

| Scholar(s) | Year | PCK Components | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Orientation to Teaching Science | Subject Matter Knowledge | Knowledge of Student understanding | General Pedagogical Knowledge | Knowledge of Instructional Strategies | Knowledge of Curriculum | Knowledge of Goals | Knowledge of Assessment | Knowledge of Resources | Knowledge of Contexts | Media for Instruction |
| | | OTS | CK | KS | PK | KIS | KC | KG | KA | KR | KCon | |
| Shulman | 1986 | | X | X | | X | | | | | | |
| Shulman | 1987 | | X | X | | X | X | X | X | | | |
| Tamir | 1988 | | | X | | | | | | | | |
| Grossman | 1989 | | | X | | X | X | X | | | | |
| Marks | 1990 | | X | X | | X | | | | | | X |
| Cochran et al. | 1993 | | X | X | | X | | | | | X | |
| Carlson | 1999 | | | X | | X | X | X | | | | |
| Magnusson et al. | 1999 | X | | X | | X | X | | X | | | |
| Gess-Newsome | 1999 | | X | X | | | | | | | | |
| Veal & MaKinster | 1999 | | X | X | | | | | | | | |
| Morine-Dershimer & Kent | 1999 | | X | X | | X | | X | X | | X | |
| Loughran et al. | 2001 | | X | X | | X | | | | | | |
| Hashweh | 2005 | | X | X | | X | X | X | | X | X | |
| Park & Oliver | 2006 | X | | X | | X | X | | X | | | |
| Lee & Luft | 2008 | | X | X | | X | X | X | X | X | | |
| Abell | 2008 | X | | X | | X | X | X | X | | | |
| Rollnick, Bennett, Rhemtula, & Ndlovu | 2008 | | X | X | X | | X | | | | | |
| Kind | 2015 | | X | X | X | | X | | X | | | |

In the last three decades, scholars depicted their understanding of the theoretical construct PCK and introduced many PCK models. A study by Grossman (1989) on understanding the development of English teachers' PCK provided an extended model that portrayed the development of PCK. Grossman developed this model by reviewing the literature on PCK and using it to organize the PCK of her participant English teachers. She included within PCK: (a) knowledge of goals, (b) knowledge of students' understanding, (c) knowledge of instructional strategies, and (d) curricular knowledge. Grossman also tried to develop links between PCK and other types of teacher knowledge, including subject matter knowledge, general pedagogical knowledge, and knowledge of contexts to characterize the development of PCK. Similarly, a research study by Marks (1990) on mathematics teachers' PCK resulted in another model of PCK that included new categories of teacher knowledge. According to Marks, PCK is composed of four knowledge categories: (a) subject matter knowledge, (b) knowledge of students' understanding, (c) media for instruction in the subject area, and (d) instructional processes for the subject matter. He identified a need to clarify the PCK construct, and strongly recommended expanding it to develop a clear and complete picture of PCK in different disciplinary areas. Cochran, DeRuiter, and King (1993) attempted to view teacher knowledge in the light of constructivism. They suggested a new title for the construct, *pedagogical content knowing* (PCKg), and offered a model to depict it. According to their model, PCK is the result of the integration of four other types of knowledge: (a) knowledge of subject matter, (b) knowledge of pedagogy, (c) knowledge of students, and (d) knowledge of contexts. As a result of the development of the PCK concept, all four of these knowledge aspects are also transformed.

Specific to science education, Carlsen (1999) proposed the very first theoretical conceptualization of science teachers' PCK. He presented it in the form of a visual model in a landmark edited book on science education and pedagogical content knowledge, *Examining Pedagogical Content Knowledge: The Construct and its Implications* (Gess-Newsome & Lederman, eds., 1999). He used and modified Grossman's (1989) model of PCK to devise a model that represents PCK for science teaching. Magnusson et al. (1999) conducted an extensive analysis of the literature on PCK and proposed another theoretical conceptualization of it for science teaching. Their visual model of science PCK provided an expanded view of the pedagogical content knowledge of science teachers, including five knowledge components connected in a specific hierarchical way: (1) Orientation towards science teaching, (2) Knowledge and beliefs about science curriculum, (3) Knowledge and beliefs about students' understanding of specific science topics, (4) Knowledge and beliefs about instructional strategies for teaching science, and (5) Knowledge and beliefs about assessment of science. Magnusson et al. (1999) also described the connections between these five knowledge aspects and provided a further description of each of them.

Park and Oliver (2006), and Lee and Luft (2008) provided some empirical evidence for their respective expansions of ideas about science teachers' PCK. Park and Oliver (2006) identified five knowledge components of PCK from the literature and developed a pentagon-shaped theoretical model of PCK. The five knowledge components included in their Pentagon model are the same as those identified by Magnusson et al. (1999) but are not hierarchically ranked. In Park and Oliver's (2006) model, PCK lies at the center of the Pentagon while the five knowledge aspects are at the five corners. Their in-depth research on three chemistry teachers helped them to further evolve their theoretical PCK model, adding a new component, teacher efficacy. Based on their research, they converted their pentagon model into a hexagonal model with PCK at the center and six components at the six corners. They also explored new dimensions of PCK by including the roles of teachers' qualifications, their idiosyncrasies, and their reflections: especially, reflection in action, and reflection on action.

Lee and Luft (2008) studied PCK from the perspective of four experienced science teachers, using a case study approach. They identified seven knowledge components contributing to the science PCK of these science teachers: (i) knowledge of science, (ii) knowledge of goals, (iii) knowledge of students, (iv) knowledge of curriculum organization, (v) knowledge of instructional strategies, (vi) knowledge of assessment, (vii) knowledge of resources. They further identified specific elements within these seven knowledge aspects. Their efforts to represent the PCK of individual science teachers resulted in graphic representations of the unique PCK of each science teacher (Lee & Luft, 2008) and no single visual representing science PCK was presented. **Table 2** presents a summary of various conceptulizations of the PCK construct.

**Table 2.** Summary of Prominent Research on Development and Understanding of the Construct PCK

| Scholar(s) | Year | Visual Model | Theoretical | Empirical | Remarks |
|---|---|---|---|---|---|
| Shulman | 1986 | | X | X | Developed a view of PCK based on research |
| Shulman | 1987 | | X | X | Extended view about PCK based on research |
| Tamir | 1988 | | X | | Discussed a model of PCK based on literature |
| Grossman | 1989 | X | X | X | Developed a theoretical framework for her research on PCK which became popular as Model of PCK/teacher knowledge |
| Marks | 1990 | X | | X | Developed an Empirical model of PCK- emerged from his research |
| Cochran et al. | 1993 | X | X | | Proposed a model of PCK based on literature |
| Carlson | 1999 | X | X | | Proposed a model of science PCK, a modification of Grossman's model |
| Magnusson et al. | 1999 | X | X | | Proposed a model of science PCK, based on literature |
| Gess-Newsome | 1999 | X | X | | Based on literature developed two parallel models of PCK: integrative vs. transformative |
| Veal & MaKinster | 1999 | X | X | | Theory based model of Taxonomies of PCK: topic-specific PCK, subject-specific PCK, and Discipline-specific PCK |
| Loughran et al. | 2001 | | | | New way to represent science PCK: CoRes & Pap-eRs |
| Hashweh | 2005 | X | X | X | Developed a model based on re-analysis of his previous research and merged theory. |
| Park & Oliver | 2006 | X | | X | Developed a theoretical model of PCK and validated and modified empirically. |
| Lee & Luft | 2008 | X | | X | Multiple models of individual teachers which emerged from their research |
| Abell | 2008 | | X | | Modified model from Grossman (1989) and Magnusson et al (1999) |
| Gess-Newsome | 2015 | X | X | | Developed as a result of consensus among research during PCK summit. |

In addition to including new knowledge components in PCK, researchers have also tried to make the relationships explicit between these knowledge components and found that the "boundaries of PCK are blurry" (Loughran, Mulhall, & Berry, 2004). Earlier, in 1998, Gess-Newsome and Lederman referred to similar blurred boundaries, using the analogy of an ideal gas to help argue that it is difficult to understand explicitly the role of individual knowledge components within PCK. They asserted, however, that studying individual knowledge components of PCK can help in understanding the PCK construct. This argument led towards the importance of understanding *all* the knowledge components of science teachers' PCK to explore how these individual knowledge components are organized in science teachers' overall PCK, which can help in understanding the PCK construct.

## Research on Science Teachers' PCK

The research on science teachers' PCK generally studied selected knowledge components of the science teachers' PCK, and, and researchers especially focused on studying or measuring PCK of teaching specific science topics (for example, Drechsler, & Van Driel, 2008; Henze, van Driel & Nico Verloop, 2008; Mthethwa-Kunene, Onwu, & de Villiers, 2015). This line of research has significantly contributed to the body of literature on science teachers' professional knowledge of teaching science. However, it did not add much to the understanding of the PCK construct. Nevertheless, researchers in the area of science teachers' PCK continued asserting that PCK is a topic-specific knowledge. Van Driel, Verloop, and de Vos (1998) developed a research program in the Netherlands, to create examples of TSPCK in various curriculum topics in chemistry. They did not follow any pre-existing PCK model discussed above nor did they offer a new PCK model. Alternatively, they relied on various existing definitions in the research literature. Similarly, in Australia, Loughran and his associates also considered that PCK is essentially topic-specific knowledge. Their research has documented the topic-specific science PCK of science teachers in various curriculum areas (Loughran et al., 2001, 2004, 2006). While they made important contributions towards the understanding of the topic-specific PCK of science teachers and the knowledge base of science teacher education, they did not elaborate on the existing PCK models at the time, and they preferred to employ their own unique approach to studying and documenting topic-specific science PCK. Thus, they ignored newer developments in understanding this construct. Part of the reason might be the appropriateness or sufficiency of the existing PCK models for their research goals.

In addition to these two major research groups, In **Appendix A**, I present a summary of the research studies that I reviewed about pedagogical content knowledge in different discipline areas (published from 1988 to 2018). I was particularly interested in the conceptualization of PCK, theoretical frameworks and PCK components studied by these researchers used. Most of the research on science teachers' PCK is topic-specific, predominantly qualitative in nature, and have focused on the limited knowledge aspects of PCK, mainly relying on the initial descriptions of PCK by Shulman (1986, 1987). This review also reveals that the researchers studying one or more aspects of science PCK preferred particular aspects, and considered those aspects' important. These aspects of PCK include (a) content knowledge, (b) knowledge of students' understanding and their preconceptions, and (c) knowledge of teaching strategies. This line of research provided an inadequate view of PCK by limiting the discussion on a few PCK components. Furthermore, this approach can be problematic, since limiting the study to specific PCK components runs the risk of presenting a skewed or incomplete picture of the teachers' science PCK. Also, this complication makes it hard to develop a full understanding of PCK/topic-specific PCK as a construct. Similar to the above argument, the importance of understanding *all* the knowledge components of science teachers' PCK is noticeable, particularly, to explore how these individual knowledge components are organized in science teachers' topic-specific science PCK, which can help in understanding the topic-specific science PCK construct. This points towards the need to study each knowledge category within science PCK by isolating it from the other knowledge categories.

## Identifying the Gap: Towards a Conceptual Framework

In summary, the research on understanding the PCK construct has not taken into consideration the topic-specificity of the construct. On the other hand, the research on topic-specific science PCK has not considered it important to use science PCK models to frame their research or develop their own models of TSPCK. This created a gap, and an urgent need to propose a conceptualization of topic-specific science PCK and visual models to aid that understanding. Despite ample discussions and research in the last three decades, and even with many PCK models, the literature on science PCK, did not focus on theorizing topic-specific science PCK. Recently, PCK researchers has started focusing on conceptualizing topic-specific science PCK by declaring PCK a topic-specific knowledge (Kind, 2015; Loughran et al., 2001, 2004; Park & Oliver, 2008; van Driel, Verloop, & DeVos, 1998) or by offering specific TSPCK models (Azam, 2015; Mavhunga, 2014). Muvhunga (2014) conceptualized TSPCK as the knowledge required for subject matter knowledge transformation in a particular topic, and inspired by Geddis and Woods (1997) identified five components of TSPCK: (i) learners prior knowledge, (ii) curriculum saliency, (iii), what makes the topic easy or difficult to understand, (iv) representation into powerful examples, and (v) conceptual teachings strategies. Muvhunga and Rollnick (2011) also introduced a visual model to depict the relationship between these five components of TSPCK. Despite its value in understanding science teachers topic-specific knowledge of teaching science, this TSPCK model has not considered TSPK as a contributor to TSPCK, which is a recent development in the area of science PCK. Therefore, I propose a working model based on the review of this targetted literature on PCK, particularly science PCK, a conceptual framework which I used for my Doctoral Research to analyze the data to portray topic-specific science PCK of science teachers. The following sections describe how the current theories and research on science PCK have contributed to the conceptualizing of this framework, and how it is a useful lens to explore and portray topic-specific science PCK.

## The Proposed Working Model for TSPCK

In this section, I describe a working model of TSPCK, illustrated in **Figure 1**, which is a modified form of Comprehensive Topic-specific PCK (Azam, 2015). This working model has considered ten teachers knowledge categories existing in the current PCK literature and equated them as professional knowledge bases, the idea introduced in the Model of Teachers' Professional Knowledge Including PCK (Gess-Newsome, 2015). The dark shaded rectangles arranged on the top and bottom of **Figure 1** represents the nine teachers' professional knowledge bases, while the tenth teacher knowledge base (content knowledge), contributes as conceptual understanding of a science topic, represented as two dark shaded rectangles arranged next to teacher's professional knowledge bases.

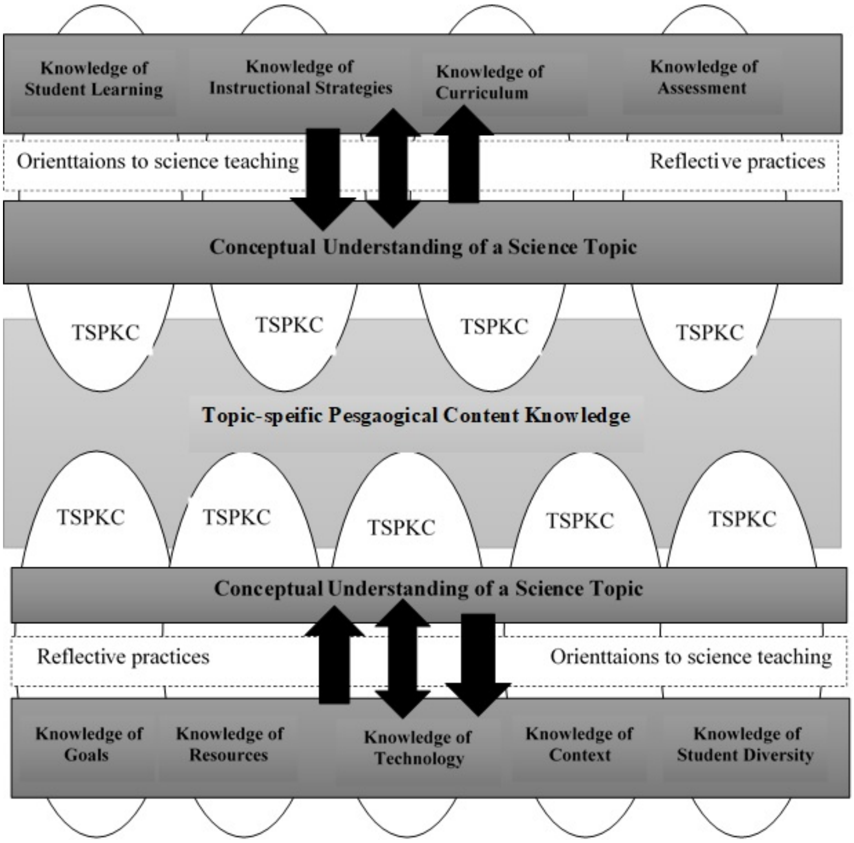


**Figure 1.** An illustrates a working model of TSPCK

This TSPCK working model keeps the possibility open to including more professional knowledge bases if introduced in the future. Teachers' conceptual understanding of a science topic, emerging from their CK, joins in with each of the nine teacher knowledge bases using one of the three processes (interaction, interpretation, or specification) and give rise to topic-specific professional knowledge (TSPK) components represented as nine ovals. Science teaching orientations and reflective practices of a teacher play a role in shaping these TSPK components. The dotted rectangles between the professional knowledge bases and conceptual understanding of a science topic represent a science teacher's orientations towards teaching this topic and their reflective practices related to teaching and learning this specific science topic. It is these topic-specific knowledge components, which constitute a science teacher's TSPCK. **Table 3** presents a brief description of each of the nine TSPK components.

**Table 3.** A Brief Description of the Nine TSPK Components

| Professional Knowledge Bases | CK | TSPCK components | Brief Description |
|---|---|---|---|
| Knowledge of Student Learning | Conceptual Understanding of a Science Topic | TSPCK of Student Learning | Views and understanding of students' alternative ideas of a specific science topic |
| Knowledge of curriculum | | TSPCK of the science curriculum | Views and understanding of science curriculum related to a specific science topic |
| Knowledge of Goals | | TSPCK of goals of science teaching | Goals of teaching a specific science topic |
| Knowledge of Assessment | | TSPCK of assessing science learning | Views and Ideas about assessing a specific science topic |
| Knowledge of Instructional Strategies | | TSPCK of instructional strategies | Repertoires of instructional strategies to teach a specific science topic |
| Knowledge of Resources | | TSPCK of science teaching resources | Knowledge and use of teaching resources to teach a specific science topic |
| Knowledge of Technology | | TSPCK of technologies for science teaching | Views and ideas about using technology to teach a specific science topic |
| Knowledge of Student Diversity | | TSPCK of student diversity for inclusive science education | Views and ideas about addressing student diversity to teach a science topic |
| Knowledge of Contexts | | TSPK of teaching science in the various context | View and ideas about teaching a specific science topic in various teaching contexts |

The light-shaded central rectangle represents comprehensive TSPCK, composed of the many TSPCK components, connected together uniquely to turn into a special amalgamation that is used by a science teacher in a specific pedagogical situation. This type of integration of teacher knowledge categories has been carried out by Park and Chen (2012). The composition of this amalgam is Idiosyncratic for an individual science teacher, representing personal TSPCK of that teacher. A teacher's thinking involves complex cognitive processes. This proposed working model does not claim to depict all of those cognitive processes fully but serves as a heuristic for understanding TSPCK in various pedagogical situations, whether conceptual or practical.

In the following five sub-sections, I critically analyze PCK literature to describe features of this TSPCK conceptualization as a knowledge category within TSPK.

*First*, I provide a rationale for considering many teacher categories than fewer to describe the composition of TSPCK. As described above, developmental studies of PCK—research studies with a focus on understanding and developing the PCK construct (Lee & Luft, 2008; Park & Oliver, 2008)—have reported it as an interaction of many different categories of teacher knowledge, as opposed to only the two categories that Shulman (1986) proposed. Although Abell (2008) corroborated the conceptualizations of many other researchers and affirmed that PCK is an amalgam of *many* knowledge categories at the intersection of content knowledge and general pedagogical knowledge, these *many* knowledge categories are not yet consistently reported in the existing literature. Following Abell (2008), I see PCK as an amalgam of multiple teacher knowledge categories. However, I elaborate by identifying and describing the knowledge categories using ten topic-specific teacher knowledge components. Eight teacher knowledge categories are identified in the existing literature as contributing to the PCK in various combinations: (i) subject matter knowledge, (ii) knowledge of student learning, (iii) knowledge of instructional strategies, (iv) knowledge of resources, (v) knowledge of curriculum, (vi) knowledge of goals, (vii) knowledge of assessment, and (viii) knowledge of teaching contexts. I propose to consider a ninth category, (ix) knowledge of technology, which has been discussed in other literature as part of technological pedagogical content knowledge. I also propose a tenth teacher knowledge category contributing to TSPK, (x) knowledge of student diversity. Moreover, I suggest considering further knowledge categories in the future to contribute to and be part of TSPK. However, I do not propose that all of these teacher knowledge categories are included in TSPCK. Only a topic-specific knowledge component (TSKC) of any of these knowledge categories may become part of TSPCK guided by a particular pedagogical situation depending on the topic to be taught and the context of teaching. This leads to the argument that Science PCK in the context of a specific science topic may include a different set of topic-specific knowledge components. For example, topic-specific science PCK related to force and motion may look different from topic-specific science PCK related to evolution or chemical reactions. I argue against limiting teacher knowledge categories within TSPCK, without the empirical evidence. And, I propose to use the broader view of science TSPCK when studying it in the context of various science topics, so that to provide evidence of the presence or absence of various knowledge components within TSPCK.

*Second*, I consider the place of content knowledge within TSPCK. This conceptual framework is different from the previous ones by virtue of the placement of content knowledge understanding rooting from a teacher's subject matter knowledge (SMK), which has been placed outside of other teacher knowledge categories, and integrates with each one of these teacher knowledge categories to results into several TSPCK components. I argue that this placement of content knowledge (CK) is not only close to the initial interpretation of PCK by Shulman (1987) but also appears to be consistent with most of the discussions on relationship of SMK and PCK and its significance for teaching (e.g., Geddis, 1993; Ozden, 2008; Tamir, 1988). As Geddis (1993) pointed, teaching is content-specific and effective teachers have capabilities to teach a specific content (e.g., fraction, electricity, chemical reactions, and ovulation). Teachers develop these capabilities over the time by integrating their content knowledge understanding with other pedagogical knowledge. Therefore, this conceptual framework keeps CK outside of other teacher knowledge categories and deliberates the process of 'integration' between CK and other teacher knowledge categories.

*Third*, I describe the nature and development of TSPK components, an amalgam of which results into TSPCK. This conceptual framework further describes that TSPK components are the result of 'integration' between CK and another teacher nine teacher knowledge categories identified above, and this integration process may have three forms: (a) interpretation, (b)synthesis, and (c) specification. Many scholars in PCK view its development as the transformation of SMK (Ball, 1988; Geddis, 1993, 1997). Similarly, Muvhunga, (2014) described TSPCK as subject matter knowledge transformation. However, the literature on PCK shows that PCK is not always a result of the transformation of SMK. According to Marks (1990) transition from subject matter knowledge to pedagogical content knowledge involves three processes: *Interpretation,* *specification,* and *synthesis*. *Interpretation* is close to what Shulman (1987) called *transformation,* Ball (1988) called *representations, and* Veal and MaKinster (1999) named "translation." Mark also found that some aspects of PCK are derived from general pedagogical knowledge, and he called this process as a *specification* which helps the transition of general pedagogical knowledge (PK) into PCK through a process of the specification. Similarly, another process for transition from other knowledge categories to PCK is *synthesis* where subject matter knowledge and general pedagogical knowledge or any other two or more knowledge components combine together to become part of PCK. In the following sections, I provide an overview of these three processes as conceived in science education research:

***Interpretation.*** The processes of Interpretation or transformation of SMK into PCK became popular when Shulman's (1986, 1987) conception of PCK was unpacked by construing his definitions. For example, Geddis, Onslow, Beynon, and Oesch (1993) considered PCK as the knowledge that assists in transforming SMK into forms that are accessible to students, and Carter (1990) viewed PCK as what teachers know about SMK and how they transform it that knowing into curriculum events in their classrooms. Muvhunga (2014) used the idea of transformation to define TSPCK, and used Geddis et al., conceptualization of PCK to inform their TSPCK model.

***Synthesis.*** The process of synthesis, as conceived by Mark (1990), is most commonly called as integration, and became popular when the concept of PCK started expanding and researchers introduced new teacher knowledge components (e,g., knowledge of curriculum, knowledge of instructional strategies, knowledge of goals, knowledge of student understanding, knowledge of assessment, knowledge of context, knowledge of media or teaching resources, knowledge of subject matter) as constituent parts of PCK, based on empirical research (Hashweh, 2005; Lee & Luft, 2008; Loughran et al, 2001; Park & Oliver, 2008) or personal experiences (Abell, 2007; Cochran, DeRuiter, & King, 1993; Magnusson, et al., 1999, Gess-Newsome, 2015). At the center of this expanded view of PCK is *integration* (Loughran, berry & Mulhall, 2006; Park & Oliver, 2012; Van Driel, De Jong, & Verloop, 2002) or synthesis (Mark 1990; Hashweh, 2005).

***Specification.*** The process of specification, as identified by Mark (1999) is a transition of general pedagogical knowledge (PK) into PCK. The idea of the *specification* has not received much attention from the science education researchers. The above three distinctions pointed that the prevailing conception that TSPCK is derived only from subject matter knowledge is not the only reality, but there are other possibilities that need to be considered for any conceptualizations of TSPCK.

This conceptual framework uses Mark's (1990) three processes (Interpretation, synthesis, and specification) as possible ways to integrate CK and nine other teacher knowledge categories to describe the development of TSPK components, which amalgamate to shapes TSPCK of a science teacher. **Figure 2** present the summary and symbols devised to represent the processes of interpretation, specification, and synthesis of content knowledge understanding and other teacher knowledge categories, such as knowledge of goals, resulting into TSPCK component.

| Possible Processes | Symbol | | | TSPCK Development |
|---|---|---|---|---|
| Interpretation | CK | → | PK Base | Content knowledge understanding is transformed into a professional knowledge base. |
| Specification | CK | ← | PK Base | The transition of a professional knowledge base to a specific science topic |
| Integration | CK | ↔ | PK Base | A professional knowledge base synthesized with content knowledge understanding |

**Figure 2.** Three processes of development of TSPCK components

The purpose of these symbols is to make these processes visible by focusing on each teacher knowledge category at a time. However, I acknowledge that in pedagogical situations, many TSPCK components combine together to become a part of a teacher's TSPCK.

*Fourth*, as viewed by Shulman (1987), I affirm that these TSPK components amalgamate together to shape TSPCK of a science teacher. Research on science PCK has tried to understand the process of amalgamation and captured how various teacher knowledge categories connect together to develop PCK (e,g., Lee & Luft, 2008; Magnuson et al. 1998; Park & Oliver, 2008; Park & Chen, 2012). Lee and Luft (2008) studied the PCK of science teachers who were teaching topics in various subject areas. On the other hand, Park and Oliver (2006) studied the PCK of chemistry teachers teaching various chemistry topics and found a more consistent representation of their PCK, while Lee and Lufet (2008) presented different representations of science teachers' PCK. Park and Chen (2012) developed PCK maps of science teachers while teaching different science topics, and this is interesting to notice that the PCK maps of different science teachers teaching the same science topics were quite similar, in some cases the same. So, studying science teachers TSPCK may help us unpack the complex process of amalgamation of TSPCK components, by revealing how these knowledge components connect together in a pedagogical situation to assist science teachers to teach a science topic effectively to a group of students.

*Fifth*, I discuss the nature of TSPCK and the role of experience. Teaching the same science topic over a period, TSPCK components, which exists as isolated bits of knowledge, are converted into well-amalgamated TSPCK, which represents a unified knowledge. An experienced science teacher will likely have more well-developed TSPCK since they have had more chances to teach a particular science topic as well as opportunities to reflect on their teaching, as compared to a novice science teacher who has had fewer teaching opportunities and therefore fewer opportunities for reflection. The opportunity to teach the same topic numerous times, and then reflecting on the experience can help a teacher develop well amalgamated TSPCK, and becomes a distinct aspect of their professional knowledge of teaching science. Moreover, well amalgamated TSPCK is stored in a teacher's memory as a holistic bundle of knowledge and skill, and therefore, can be accessed through the narration of experience, pointing to the narrative nature of TSPCK (Gudmundsdottir, 1990, 1991, 1995). Shank (1990) developed an understanding of the relationship between stories and memories; he stated that teachers' remembered-stories are recreated from the recalled "gist of the stories." Using Hashweh's (2005) term "teachers' pedagogical constructions" (TPCs), teachers' stories represent pieces of knowledge about teaching a specific science topic. While trying to unpack the PCK amalgam, Hashweh (2005) argued that a teacher's PCK is a collection of TPCs, and thus likely takes the form of events and incidents. Therefore, researchers can access science teachers' stories— or their pedagogical knowledge constructions (TPCs) as suggested by Hashweh—by engaging them in meaningful conversations and listening to the remembered gist of their stories about planning and teaching a specific science topic.

## DISCUSSION AND CONCLUSION

The purpose of this targeted litterer review was to conceptualize TSPCK in the light of previous discussions and research on science PCK as well as the new developments such as the consensus model of PCK. Topic-specific professional knowledge (TSPK) is a relatively new conceptualization in the literature on science PCK and added a new layer to the complexity of understanding science PCK. Gess-Newsome (2015) provides an initial conceptualization of TSPK and how it is different from PCK. The TSPCK working model further elaborated the concept of TSPK by identifying TSPCK components and presenting possible ways for these components to emerge or develop. Gess-Newsome (2015) viewed TSPK as codified and research-based knowledge, while PCK is the personal knowledge that teachers develop as a result of experience and also includes skills to enact that knowledge in a classroom. This TSPCK model view TSPCK as a combination of knowledge and skills, where (1) knowledge is represented by the development of TSPCK components as a result of (a) interpretation, (b) integration, or (c) specification and skills are represented by (2) integration of TSPK components by individual teachers to help students understand a science topic.

This TSPCK working model may also help in organizing professional knowledge of preservice science teachers' professional knowledge of teaching a specific science topic, and hence can be used to design learning experiences for pre-service science teachers. This working model may provide guidelines for the development of the interview questions or TSPCK items to access and assess science teachers' TSPCK. To access and study the PCK of science teachers, Abell (2007) recommended that interview questions should be designed around knowledge categories within the PCK construct, and this model suggest to develop interview questions around TSPK components described above. Interview questions developed around TSPK components may encourage science teachers to talk about their experience of teaching a specific science topic encompassing how they integrate this particular topic with other knowledge areas/components revealing aspects of their topic-specific science PCK.

The comprehensive TSPCK is a working model offered to PCK community to critique and further develop the idea of TSPK. This working model can be used in future research to study science teachers TSPCK, and develop assessment tools in science topic areas to measure TSPCK. For developing a valid instrument to assess

TSPCK of teachers in science topic, there is a need to clarify the TSPCK construct, and this framework can provide a comprehensive construct covering different aspects of teachers' TSPK and TSPCK, hence designing a valid measure of these knowledges.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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# APPENDIX A

## Summary of the Research on Science Teachers' PCK

| Year | Journal | Researchers / Context | Purpose | Subject Area/Topic | PCK Components Studied |
|---|---|---|---|---|---|
| 1994 | JRST | Clermont, C. P., Borko, H. & Krajcik, J. S.<br><br>USA | To examine the PCK of experienced and novice chemistry demonstrators. | Chemistry / Density & Air pressure | Knowledge of instructional strategy (demonstration) |
| 1998 | JRST | Van Driel, J. H., Verloop, N. & De Vos, W.<br><br>The Netherlands | To study the development of teachers' PCK concerning a specific topic. (i.e., chemical equilibrium within the context of an in-service program.) | Chemistry / Chemical Equilibrium | knowledge of students' understanding<br>knowledge of the subject matter<br>knowledge of craft |
| 1999 | EJTE | Van der Valk, T. & Broekman, H.<br><br>An international group of researchers (Oslo Maths Project )<br><br>Sweden | To develop a method (lesson preparation) to investigate PCK.<br>And see how this method simulates pre-service teachers to show their ability to develop PCK. | Mathematics, Physics, and Chemistry<br><br>Temperature and Heat Combustion<br><br>secondary | Pedagogical content knowledge ( i.e., knowledge of school subject matter and pedagogy related to that subject matter)<br><br>Pedagogy included knowledge of student's preconception, difficulties of learning, relevant representation, strategies and student activities for the specific topic. |
| 2002 | IJSE | Van Driel, J. H., De Jong, O., & Verlopp, N.<br><br>The Netherlands | To investigate the development of PCK of pre-service teachers during a semester of their post-graduate teacher education program and how this is influence by teaching experience, institutional workshops, and the mentor. | Chemistry/<br><br>Macroscopic phenomenon to Microscopic particles | knowledge of students' understanding<br><br>knowledge of the subject matter |
| 2004 | APFSTL | Loghran, J., Mulhall, P. & Berry, A.<br><br>Australia | To develop a research approach to access and portray PCK of science teachers. | General Science /<br><br>Particle Theory | Knowledge of content (includes implicitly curricular knowledge of the topic, knowledge of student's understanding)<br><br>knowledge of pedagogy (includes knowledge of representations, analgise and teaching strategies ) |
| 2005 | RISE | De Jong, O., Van Driel, J. H. & Verloop, N.<br><br>Netherlands | To study the development of PCK (use of particle models) in the context of a specific course module within a chemistry teacher education program | Chemistry /<br><br>Relationship between physical and chemical processes | pedagogical content knowledge (using particle model) |
| 2006 | TTE | Johnstone, J. & Ahtee, M.<br><br>England & Finland | To explore the connection between teacher's attitudes, subject knowledge and the construction of P<br>CK in initial teaching. | Physics /<br><br>Air is matter and so it has weight<br><br>Primary | Subject matter knowledge<br><br>pedagogical content knowledge<br><br>Attitudes towards science teaching |
| 2008 | RISE | Drechsler, M. & Van Driel, J.<br><br>Sweden | To investigate teacher' knowledge of student's difficulties in understanding acid-base chemistry and their knowledge of<br>teaching strategies, (especially their use of models of acids and bases) in their teaching practice | Chemistry / Acids & Bases<br><br>Upper Secondary | Pedagogical Content Knowledge<br><br>knowledge of students understanding<br><br>knowledge of teaching strategies ( models of acid and bases) |
| 2008 | ESTP | Ozden, M.<br><br>Turkey | To investigate the effect the amount and quality of content knowledge of student teachers on their PCK in context of preparing lesson plans. | Chemistry/ Phases of Matter<br><br>Primary | Knowledge of content<br>Knowledge of students' understanding (conceptual difficulties)<br>knowledge of curriculum<br>knowledge of teaching methods (instructional strategies)<br>Orientation towards teaching |
| 2008 | IJSE | Lee, E. & Luft, J.<br><br>USA | To explore the concept of PCK with experienced mentor teachers | Chemistry, Biology, Physics<br><br>Different Topics in relevant subject area | Pedagogical content knowledge which is composed of<br>Knowledge of science,<br>Knowledge of goals<br>Knowledge of students<br>Knowledge of curriculum organization<br>Knowledge of teaching<br>Knowledge of assessment<br>Knowledge of resources |
| 2008 | RISE | Park & Oliver | To rethink the conceptualization of pedagogical content knowledge based on our descriptive research findings and to show how this new conceptualization helps us to understand teachers as professionals | Chemistry<br><br>High School | Knowledge for teaching<br>Knowledge of student understanding<br>Subject matter knowledge<br>Pedagogical content knowledge<br>Teacher efficacy<br>Teacher professionalism |
| 2008 | IJSE | Henze, I., Van Drial, J. H. & Verloop, N.<br><br>The Netherlands | To investigate development (change) of PCK of teachers, over the time of three years after the introduction of a new curriculum in the context of teaching a chapter on the solar system | Earth Sciences, Solar System, | Subject matter knowledge (of models regarding acid and bases)<br><br>knowledge of students difficulties and<br><br>knowledge of using textbooks |

| Year | Journal | Researchers / Context | Purpose | Subject Area/Topic | PCK Components Studied |
|---|---|---|---|---|---|
| 2009 | IJSE | Kapyla, M., Heikkinen, J. P., & Asunta, T. | The research aimed to investigate the effect of the amount and quality of content knowedge on pedagogical content knowledge (PCK). | Biology/ Photosynthesis and plant growth | Knowledge of subject matter<br>Knowledge of teaching strategies<br>Influence of pedagogical content knowledge |
| 2009 | ESTP | Usak, M. | To explain prospective science and technology teachers' pedagogical content knowledge (PCK) about the cell. | Biology/ Cell topics | Pedagogical Content Knowledge<br>Pre-service science and technology<br>Subject matter knowledge (regarding cell topics) |
| 2013 | IJSME | Schemelzing, S., Van Driel J. H., Juttner, M.,Brandenbusch, S., Sandmann, A., & Neuhaus, J.B. | To develop standardized measures of biology teachers' topic-specific PCK that are labor-efficient. | Biology/ Cardiovascular system | Pedagogical Content Knowledge<br>Teachers Assessment<br>Teacher Knowledge |
| 2014 | EQ | Rollnick, M., & Mavhunga, E. | To determine the teacher knowledge bases associated with the ability to transform content knowledge in the topic of electrochemistry for effective learning. | Chemistry: Electrochemistry | Pedagogical Content Knowledge<br>Subject matter Knowledge (regarding electrochemistry)<br>Topic-specific PCK |
| 2011 | EJTE | Usak, Uzak, M., Ozden, M., & Eilks, I. | To evaluate selected aspects of beginning Turkish science student teachers' subject matter knowledge (SMK) and pedagogical content knowledge (PCK) concerning chemical reactions for initial science teaching. | Chemistry/ Chemical Reaction | subject matter knowledge, pedagogical content knowledge, beliefs about science teaching of student teachers |
| 2012 | IIJSME | Seung, E. | To describe how the PCK of physics TAs in the M&I course was developed and enacted. | Physics/ Matter and interaction | Pedagogical content knowledge, Subject matter knowledge<br>Topic-specific PCK |
| 2015 | IJSE | Mthethwa-Kunene, E., Onwu, G.O., & De Villiers, R. | To explore the pedagogical content knowledge (PCK) and its development of four experienced biology teachers in the context of teaching school genetics. | Biology/ Genetics | Pedagogical content knowledge<br>Topic-specific PCK<br>PCK development |
| 2016 | IJSE | Davidowitz, B., Potgieter, M. | To determine the proportion of the variance in PCK accounted for by the variance in CK. | Chemistry, Organic chemistry | Topic-specific PCK<br>Pedagogical content knowledge |
| 2017 | RISE | Melo-Nino, L, N., Canada, F., & Mellado, V. | To obtain an image of the participants' teaching of electric field and the inherent complexities that go with that. | Physics/ electric fields | Topic-specific PCK<br>Pedagogical content knowledge<br>Science teachers' professional learning |
| 2018 | CERP | Nur-Akin, F., & Uzuntiriyaki Kondakci, E. | To examine the interactions among pedagogical content knowledge (PCK) components of novice and experienced chemistry teachers in teaching reaction rate and chemical equilibrium topics in this qualitative multiple-case design study | Chemistry/ Reaction rates and chemical equilibrium | Topic Specific PCK<br>Knowledge of learner<br>Knowledge of Curriculum<br>Pedagogical content knowledge |

**Note:**

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| JRST | Journal of Research in Science Teaching |
| IJSCE | International Journal of Research in Science Education |
| RISE | Research in Science Education |
| IJSME | International Journal of Science and Mathematics Education |
| APFSTL | Asia- Pacific forum of science learning and teaching |
| EJTE | European Journal Of teacher education |
| TTE | Teaching and teacher education |
| ESTP | Educational Science: Theory & Practice |
| EQ | Educación Química |
| ESTP | Educational Sciences: Theory & Practice |
| CERP | Chemistry Education Research and Practices |