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KNOWLEDGE BASE FOR TEACHING AND PEDAGOGICAL CONTENT KNOWLEDGE (PCK): SOME USEFUL MODELS AND IMPLICATIONS FOR TEACHERS' TRAINING

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Abstract

In recent years the profession of teaching has reached a maturity to the point of being considered a producer of own knowledge necessary to the practice. The teacher is no longer seen as a technician, but as an intellectual actor and the specialized literature advocates teaching as a profession, and it recognizes that the teacher has "knowledge base", a set of skills that are developed during his teaching activity. The Pedagogical Content Knowledge (PCK) is a concept that seeks to represent the teachers' professional knowledge and it has been widely used in the literature about teachers' knowledge. It has proved a fruitful model for investigations aimed to document the knowledge that makes one a good teacher. Despite the relevance that the PCK is, the consensus on what is the PCK is still far from being achieved and many researches propose different models and concepts for the PCK, sometimes conflicting. Many works brings the PCK and speak of it as if it were a clear concept and do not clarify which model / conception are using, which makes investigations on the PCK difficult and ends up attracting a lot of criticism. Thus, this study aims to look critically at the various models proposed in the literature most used and point differences and similarities so that an overview can be built with more insight and analyze their use and validity. The study will also present some ways to have access to PCK and the relation between PCK and teacher education is also discussed.
Key words: *knowledge base of teaching; pedagogical content knowledge; professional knowledge; teachers' education; teachers' knowledge.*

Introduction

Every profession has a body of knowledge that set it apart from others and makes people who master such skills considered suitable professionals to exercise the profession. Interestingly, for the profession that educates all other, the teachers; there is no consensus about the body of knowledge necessary to be a teacher, even about its existence. Common sense is that to be a teacher just knows some specific content. Consequently, the widespread idea that other skills are not needed beyond the specific content to be a teacher. This situation makes the teacher profession often a temporary one and shows inconsistency between the social and economic depreciation of the profession with the responsibility and training required. Although knowledge of the specific content (Chemistry, Biology, Portuguese, Geography, etc.) is the primary task of being a teacher, your domain is only part the story, since specific skills for teaching are long recognized as necessary (Kind, 2009). In this sense, Montero (2001) states that "[...] teaching goes far beyond what you teach and encompasses a number of less visible and less socially recognized activities performed by teachers with an empty room." Such activities include aspects of planning and assessment, and these are the activities to be considered during the preparation and analysis of knowledge of teachers.

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Bucat (2005) follows this same line to mention that "[...] There is a vast difference between knowing about a topic (content knowledge) and knowledge about the teaching and learning of that topic (pedagogical content knowledge" (Bucat, 2005, p. 2). Nowadays, teaching as a professional activity of teachers is seen as a set of actions intentionally set by a teacher, to promote the students' learning of concepts, procedures and attitudes in the context of an institution - the school - which affects the teaching activity and is affected by it (Montero, 2001).

The Pedagogical Content Knowledge (PCK) is a concept that has come to represent the knowledge that teachers use in the teaching process (Kind, 2009). In this sense, if you can identify PCK, the understanding of what it means to *be a good teacher* could be enhanced and could facilitate the promotion of PCK development in pre-service teachers in ways of more intentional and consistent manner.

The PCK is a construct that has been widely used in the literature about teachers knowledge _ and it is considered the specific professional knowledge and also it has proved to be a fruitful model for investigations aimed to document the knowledge that makes one a good teacher. Despite the relevance that the PCK is, the consensus on what is the PCK is still far from being achieved and many researches propose different models and concepts for the PCK, sometimes conflicting. Many works brings the PCK and speak of it as if it were a clear concept and do not clarify which model / conception are using, which makes investigations on the PCK difficult and ends up attracting a lot of criticism. Thus, this study aims to look critically at the various models proposed and most used in the literature and point differences and similarities so that an overview can be built with more insight and analyze their use and validity.

In the context of teacher education a central issue is the definition of what are the skills that a teacher needs to know to teach (*knowledge base*). As already mentioned, for many decades, it was believed that what the teacher needed to know in order to teach was the specific content. In practice, however, is not only content what characterizes a good teacher. If so, all university teachers, researchers and experts in their content, should be excellent teachers. However, it is known that this is not at all a truth and, on the contrary, the inefficiency of experts in the classroom is one of the major complaints of the students in general (Kind, 2009).

From the 1980s becomes an effective appreciation of the practical understanding of what it is that knowledge of teachers. Accordingly, a series of models representing the knowledge of teachers has been produced in an attempt to describe and delineate a body of knowledge base for teaching (Elbaz, 1983; Shulman, 1986, 1987; Wilson, Shulman, Richert, 1987; Freire, 1985, 1996; Tardif, 2002; Gauthier, 1998, Pepper, 2008). There is a consensus that for teaching practice is required knowledge from different sources, namely: personal knowledge, knowledge from initial and continuous training knowledge of curriculum and knowledge of professional practice.

Research on teachers' knowledge produced a substantial change from the study of teaching in order to provide prescriptions for teachers to a situation that is the recognition of the knowledge of teachers (Montero, 2001). Thus, a shift occurs from a concern for propositional and generalizable knowledge to an interest in a practical and personal knowledge, expressed through metaphors, stories, pictures, etc. Several authors have positioned themselves in this second part, including Shulman (1986), Morine-Dershimer (1989), Clark and Peterson (1986), among many others.

According to Fenstermacher (1994), two forms of research on teaching practice coexist: formal and practical research, performed by different agents that give rise to two conceptualizations about the knowledge of teachers. The *formal knowledge* refers to knowledge of teaching as something external to teachers, obtained by expert researchers and provided to teachers through initial and continuing training. This type of knowledge intended to serve as a prescription to guide the work of teachers. *Practical knowledge* is the result of what teachers know from their professional expertise. This author presents a severe criticism and raises questions about what is this kind knowledge we are naming as practical knowledge from the epistemological point of view.

In the literature on teacher knowledge, various names have been used, each indicating one aspect of that relevant knowledge (Henze, Van Driel, Verloop, 2007). Together, these designations give an overview of how teachers' knowledge has been investigated in the last decades (Verloop et al., 2001). The most commonly used names are personal knowledge (Connelly, Clandinin, 1985), situated knowledge (Brown, Collins, Duguid, 1989), knowledge of professional, craft knowledge (Shimahara, 1998), action-oriented knowledge (Carter, 1990), tacit knowledge (Eraut, 1994), among others. In this work the expression teachers' knowledge is used to indicate all the teachers' knowledge and beliefs that influence their teaching practices as assigned by Verloop, Van Driel and Meijer (2001).

Practical Knowledge

There is consensus in the literature that practical knowledge results from the recognition of professional knowledge of teachers, valuing their contribution to the construction of knowledge about teaching, regarding it as well as an intellectual activity. This means that one starts from the assumption that the teacher builds knowledge in your classroom in contact with their students that is distinct from that formal knowledge learned in the Academia. Schön (1992), follower of Deweys' ideas, is considered one of the authors who contributed to enhancing the practical knowledge through its proposal for an epistemology of practice.

According to Carter (1990) the characteristics of the professional practice of teachers seem to require an idiosyncratic, situational, intuitive knowledge, highly tentative and hardly fits the categories of basic and applied (formal knowledge), in other words, knowledge own of technical rationality. In this sense, several authors have performed propositions about the components of practical knowledge. Elbaz (1983) identifies five components: knowledge of yourself, the environment, the content, the development of curriculum and instructional strategies. Shulman (1987) and Wilson, Shulman and Richert (1987) defines seven categories for teacher knowledge: content knowledge, general pedagogical knowledge, curriculum, pedagogical content knowledge, students and their characteristics, educational contexts, and knowledge of purposes, aims, objectives and educational philosophies. Putnam and Borko (1997) recognize three: general pedagogical knowledge, content and pedagogical content. Calderhead (1996) identifies five components: knowledge of yourself, subject matter knowledge, students' knowledge, curriculum and teaching methods. Grossman (1990) systematizes Shulman's proposal on four components: content knowledge, general pedagogical knowledge, pedagogical content knowledge and context knowledge.

In the same article of the year 1987, Shulman presents the Model of Pedagogical Reasoning and Action (MPRA, Figure 1). This model represents how the practical knowledge of teachers can be developed and points to the relevance of reflection in this process.

Regarding to the MPRA model Shulman explains that most of the teaching begins by some form of "text", a textbook, script or other material that the teacher or students would like to understand. According to the MPRA proposed by him, starting from a textbook, educational goals, and a set of ideas, the pedagogical reasoning and action involve a cycle through activities of *comprehension, transformation, instruction, assessment and reflection*. The starting point and end of the process is an act of understanding. Because of its procedural nature, the MPRA requires reasoning processes of the teacher on the content for teaching that are in continuous restructuring. Their dynamic is being enriched by the context in which it happens as a result of social interactions that educational activity implies and distinct periods that characterize the teaching practice. The MPRA is thus a dynamic and cyclical model of teacher reflection and action. This model seeks to embrace the knowledge that the teacher has on the subject matter and on methodological approaches that develops on a particular subject. At each step, a series of knowledge and skills is required. Thus, in the MPRA model Shulman represents the steps that occur in the development of professional practice of a teacher, particularly using a specific content. Shulman's contribution is to recover the "missing paradigm" and bring to the scene of

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the teachers' knowledge the specific content; however, it is tied to its pedagogical dimension. And this transformation of content into pedagogically powerful ways is what Shulman calls pedagogical content knowledge.

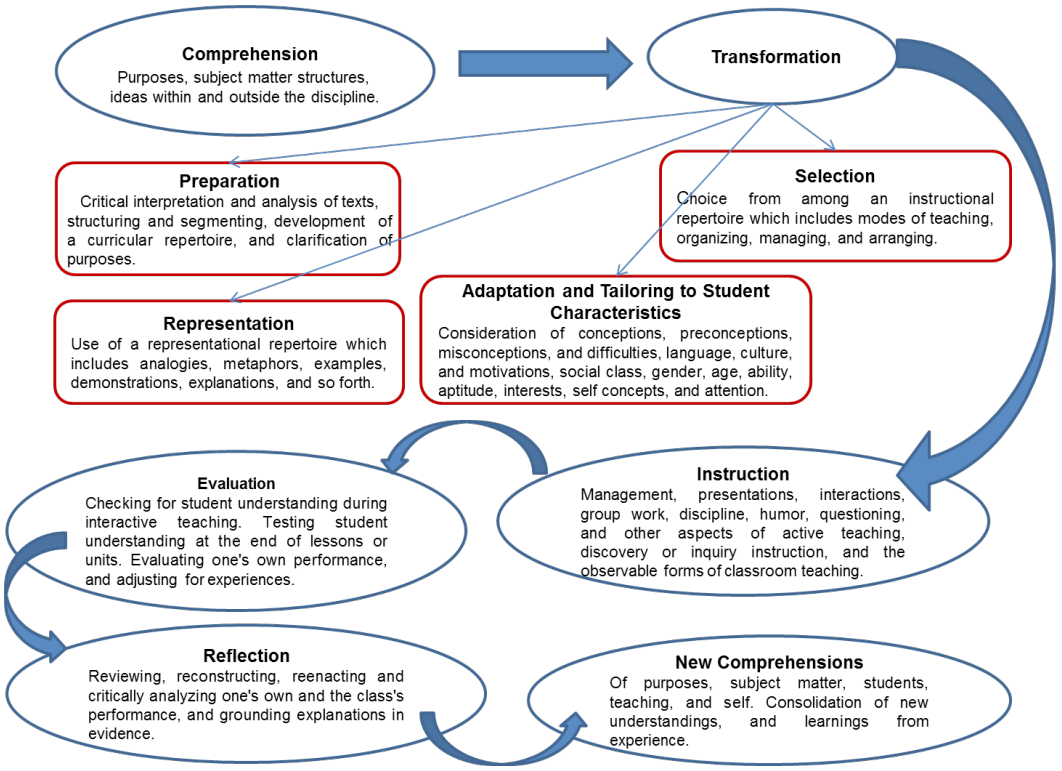

Figure 1: A Model of Pedagogical Reasoning and Action (MPRA).
Adapted from Shulman, 1987, p. 15 and Salazar, 2005.

Models of Teacher Knowledge and PCK

Shulman's Model of the Knowledge Base of Teaching

In 1986, Shulman and Sykes defined the knowledge base for teaching as "the body of understanding and skills, and device and values, character and performance that together constitute the ability to teach." They listed eight categories involving this base:

i.) General liberal education, including basic skills for reading, math, writing and reasoning
ii.) Content knowledge in the domains in which teaching will occur
iii.) Content-specific pedagogical knowledge
iv.) General knowledge of pedagogical principles and practice
v.) Curriculum knowledge
vi.) Understanding of student diversity and individual differences
vii.) Performance skills
viii.) Foundations of professional understanding (including history and policy, philosophy and psychology; cultural and cross-cultural factors; professional ethics

In the same year, Shulman (1986) proposed three categories of content knowledge for teachers, saying that the content has different facets to the teacher who has to consider: content knowledge itself; the pedagogical content knowledge; and curricular knowledge. And so the Pedagogical Content Knowledge expression (PCK) was launched by Shulman and appar-

ently came to mean a special kind of knowledge of teachers who had not previously served by any name. According to Shulman (1986) content knowledge includes: knowledge of concepts, theories, ideas, knowledge of proofs and evidences as well as practices and approaches to develop this knowledge. While the pedagogical knowledge includes the educational purposes, the methods of teaching and learning, that is, knowledge about techniques or methods used in the classroom, the nature of the target audience and strategies for assessing students' knowledge. In general pedagogical knowledge encompasses educational purposes and values and, in addition, requires a cognitive, social and developmental theory of learning and how they apply within the classroom.

Later, Shulman (1987) outlines the categories of teacher knowledge to promote understanding among its students, he considers seven types of basic knowledge that a teacher must have:

i.) Content Knowledge
ii.) General Pedagogical Knowledge
iii.) Curricular Knowledge
iv.) Pedagogical Content Knowledge (PCK)
v.) Knowledge of Learners and their characteristics
vi.) Knowledge of Educational Contexts
vii.) Knowledge of Purposes, educational purposes and educational values and their philosophical and historical bases

Shulman (1987) says that the Pedagogical Content Knowledge is that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding.

Pedagogical Content Knowledge (PCK) in the Initial Vision of Shulman

Shulman introduced the idea of Pedagogical Content Knowledge as an element of what he called a knowledge base for teaching. Key elements in Shulmans' conception for PCK are knowledge of representations of the specific content and instructional strategies on the one hand, and understanding of learning difficulties and students' conceptions of specific content on the other.

Expression of PCK was initially presented by Shulman to denote a specific type of teacher knowledge, knowledge that differentiates a teacher in a given discipline from an expert of that discipline. This expression was first named by Shulman at a conference at the University of Texas in 1983, whose title was suggestive: "The missing paradigm in the research about teaching."

What Shulman called the missing paradigm was the specific content and lack of attention that it was earning on the way to being a teacher. During his research history, the interests of Shulman focused on two main points: cognition for professional practice, especially under conditions of uncertainty as the professions of physicians and teachers; and the specificity of the domain expert. Shulman (1986) examined questions used from evaluations to select teachers over the years and realized that, historically, sometimes the programs to select teachers focused on specific content and sometimes the focus was on pedagogy. Shulman then asks whether it is always necessary to have this separation between content and pedagogy on the path to becoming a teacher.

In the 1987 article, Shulman mentions the idea of PCK for the first time referring to the intersection of content and pedagogy, and says: "[...] that special amalgam of content and pedagogy that belongs only to the universe of teachers, their special form of professional understanding." (Shulman, 1986, p. 9). For Shulman yet, is this ability to transform the content that distinguishes, for example, a chemistry teacher from an expert in chemistry. Shulman defined PCK as that knowledge:

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[...] which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*. I still speak of content knowledge here, but of the particular form of content knowledge that embodies the aspects of content most germane to its teachability. Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice. (Shulman, 1986, p. 9)

From the moment that Shulman coined the term PCK, it gained momentum in investigations of knowledge of teachers and has been widely used. PCK is now a model for investigations of knowledge of teachers. Studies of PCK suggest that this knowledge is related to the planning and instruction in the classroom. For Carter (1990), practical knowledge and PCK are two distinct categories, but interrelated in the learning of the teaching process. To this author, the PCK is a broader category that is part of professional knowledge and is more formal than the category practical knowledge, which is more personal and situational. Considering the categories of teacher knowledge proposed by Fenstermacher (1994) in *formal* and *practical*, the PCK seems to have more specific characteristics of formal knowledge than practical. Furthermore, Grossman (1990) argues that the PCK is part of practical knowledge and its construction meets the same methodological parameters. This is also the opinion of Shulman. Thus, it is still a matter of discussion whether the research program sponsored by Shulman is in the category of formal or practical knowledge. Some authors consider it as the participant of peculiarities of both, through which could be interpreted as a summary category.

The Knowledge Base of Teachers by Grossman and the Systematization of PCK

Grossman (1990), following Shulman, represented the proposed knowledge by this author emphasizing the value of content knowledge for the development of the curriculum:

[...] Content knowledge by teachers affects both what teachers teach and the way they do. [...] How active shapers of the curriculum, teachers make explicit their curriculum decisions their knowledge, interests, and values; they can pay more attention to what most dominate or have more interest and, moreover, give less importance or even avoid those contents who know less; deal thus to adapt a particular curriculum as much as possible to their own disciplinary knowledge, by selecting that in this function.

Grossman was the first to systematize the components of the knowledge base of teachers proposed by Shulman and characterized the concept of PCK in their model of teacher knowledge (Figure 2). For the author, there are four interacting components that form the knowledge base for teaching. They are: a) general pedagogical knowledge; b) subject matter knowledge; c) the pedagogical content knowledge; d) knowledge of context. In this model, the PCK occupies a central position and is seen as the transformation of pedagogical knowledge, context and content specific. Each of the components in this model also encompasses other areas of the knowledge base. Of these, the pedagogical content knowledge is one that interacts with all the others. Extracting from the model their view of PCK (Figure 2), Grossman reexamines Shulman' idea of knowledge base for teachers, including to the PCK the knowledge of the curriculum and representing in the model the hierarchy of the knowledge of the purposes for teaching an specific content in relation to other areas of knowledge encompassed by PCK (knowledge of students' understanding, knowledge of curriculum and knowledge of instructional strategies). Thus, in the Grossman model the three knowledge that make up the PCK are guided by a conception of the purposes of teachers for teaching such content. Thus, the formal and practical character of PCK is explained, since the knowledge and beliefs of teachers are present in the model.

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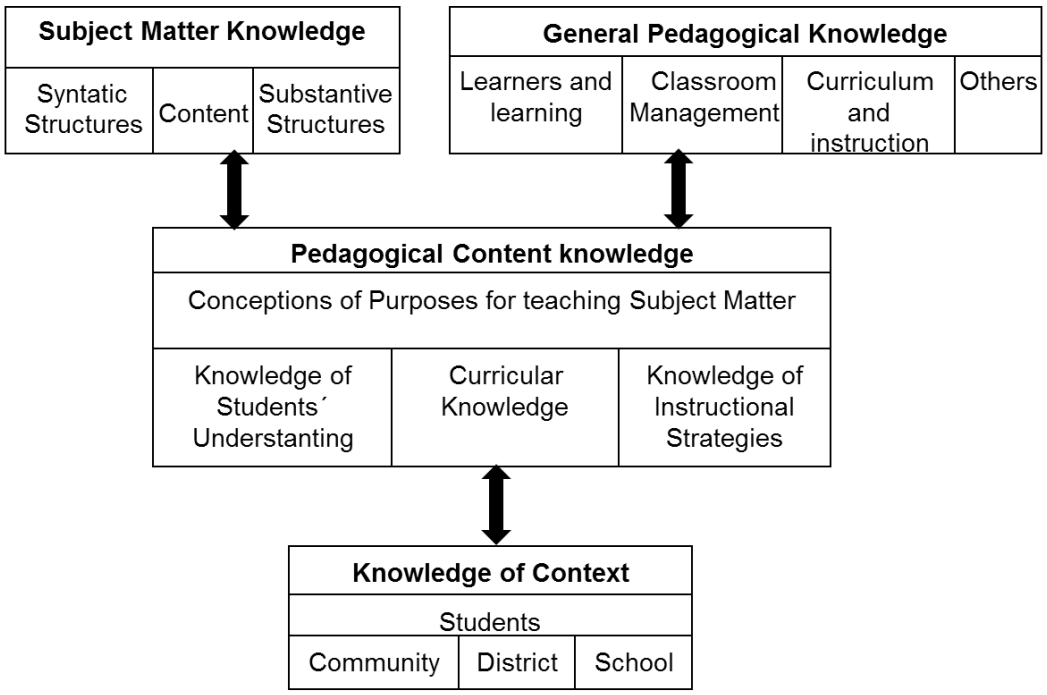

Figure 2: Model of Teacher Knowledge (Grossman, 1990).
From: Grossman, 1990, p. 5

Model of Teachers Knowledge Base of Carlsen and the PCK

Carlsen (1999) presents a proposal slightly different from Grossman to the knowledge base of teachers based on five areas of knowledge and specifying knowledge of the context in general and specific. Knowledge of general educational context includes the nation, state, community and schools, while knowledge about the specific educational context focuses on the classroom and the students to be taught. Other knowledge included in the model is: general pedagogical knowledge; subject matter knowledge: including the substantive and syntactic structures; and pedagogical content knowledge (Figure 3).

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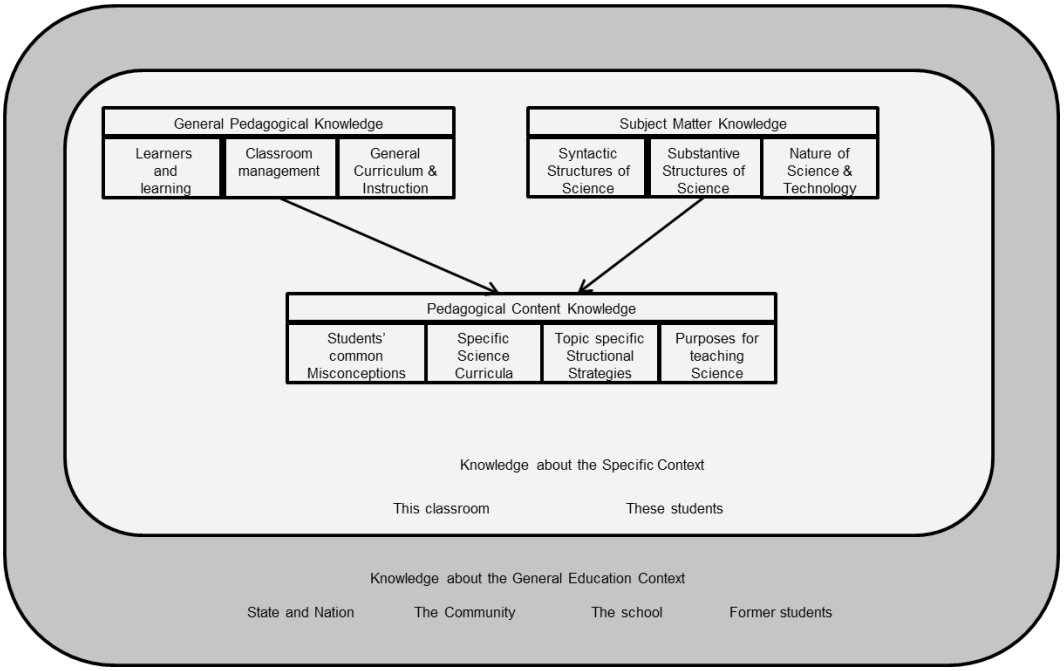

Figure 3: Domains of teacher knowledge (Carlsen, 1999).
From: Carlsen, 1999, p. 136

This model differs from Grossman (1990) for greater emphasis to the context and its unique relationship with the various areas of knowledge, in addition to represent the relationship between the broader educational context and the specific context of the classroom and individual students. Another significant difference from the Grossman model is that the purposes for teaching science are at the same hierarchical level of the other components of PCK in the Carlsen model.

PCK Model of Magnusson Krajcik & Borko

From the Grossman model of the knowledge base of teachers, many proposals have emerged to represent the core knowledge in the model of Grossman, the PCK. Among them, we highlight the model Magnusson; Krajcik and Borko (1999) that emphasizes the components of PCK for teaching science (Figure 4).

This model basically follows the Grossman's proposal, adding assessment knowledge as a component of PCK. Moreover, in this model, the "conceptions of purposes for teaching content" present in the Grossman model are replaced by "orientations for the teaching of science" in Magnusson et al. (1999). These guidelines are explained by the authors: process, academic rigor, didactic, conceptual change, activity-driven, discovery, project based science, inquiry and guided inquiry. Although the contributions of Magnusson; Krajcik and Borko model (1999) Friedrichsen; van Driel and Abell (2010) point out some criticism related to the terms used in it. According to the authors the term "orientations to teaching science" is used with different meanings in different works reported in the literature. This ambiguity, according to the authors, is the result of the origin of the term, which is defined at first as "knowledge and beliefs about the purposes and goals of science education at a given level of education", considering the teacher as participant in the process and in a second phase as "a vision or general understanding of science education ", the latter omits the role of teacher.

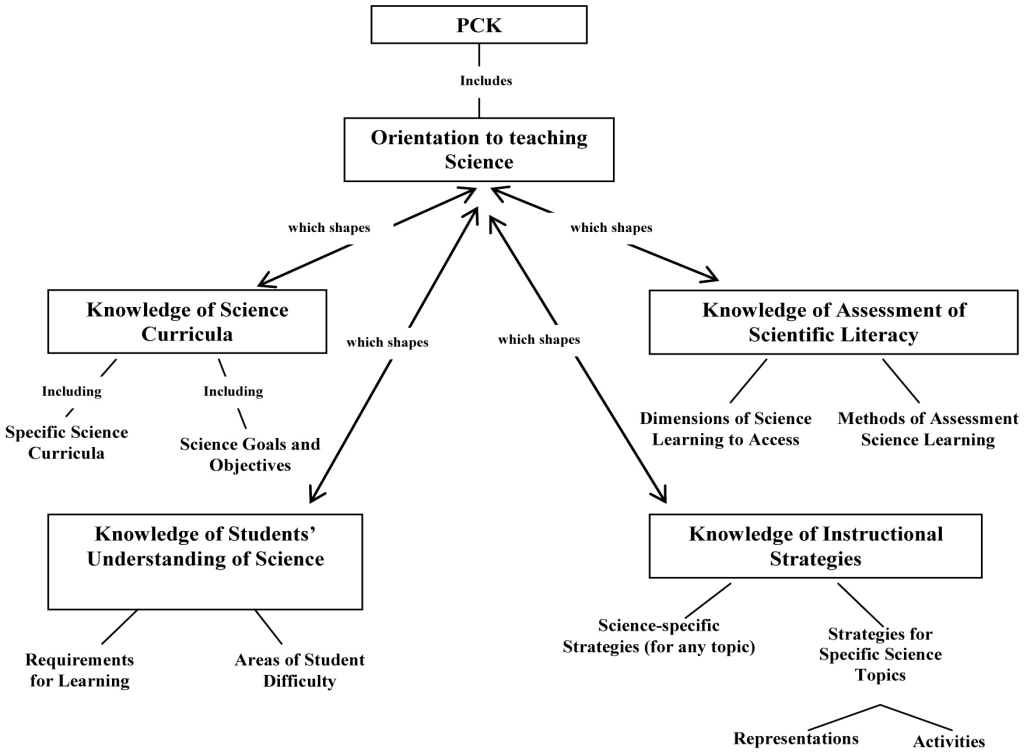

Figure 4: Components of pedagogical conent knowledge for science teaching.
From: Magnusson; Krajcik; & Borko, 1999, p. 99.

Model of PCK from Park & Oliver and this Development

In the work of Park and Oliver (2008), was added to the Magnusson's et al. model a sixth component on the efficacy of the teacher. The affective perspective has been highlighted in the literature as one of the components of PCK. The authors call this model of construction of PCK as Model Hexagonal (Figure 5). In this model is shown the emergence of teacher efficacy, the qualification of idiosyncrasy, the importance of reflection, and the recognition of the significance of students' roles as units within PCK (Park & Oliver, 2008). The efficacy component that appears in this model directs the teacher to share what he perceives to be more effective in the classroom.

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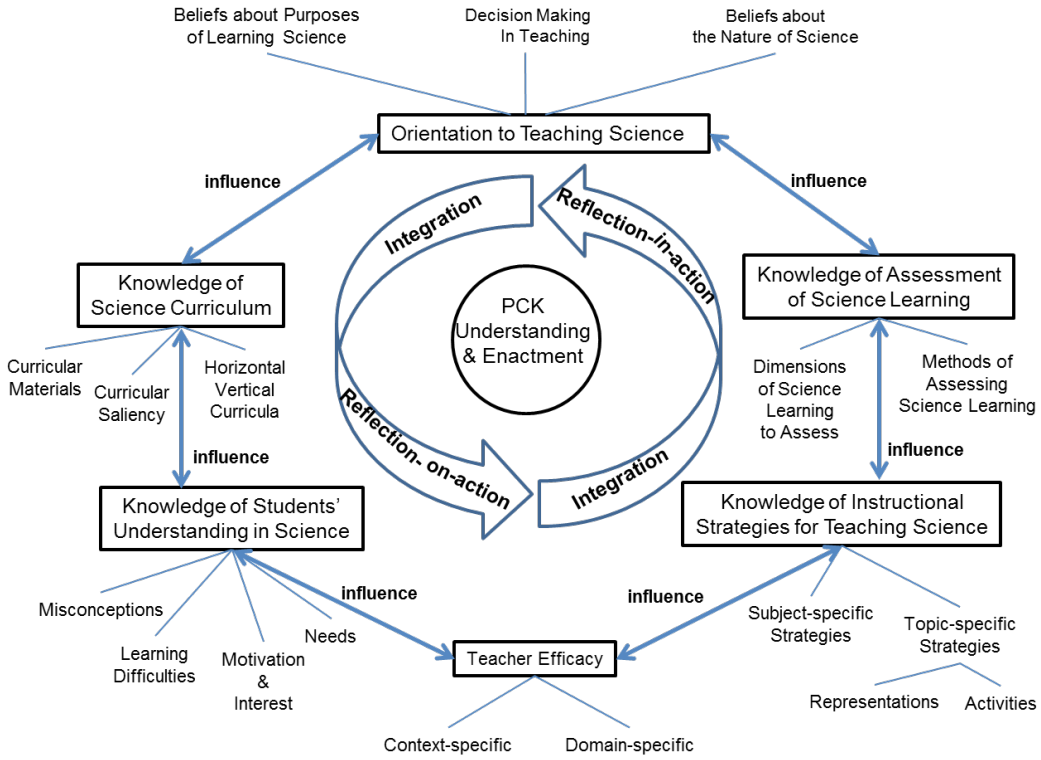

Figure 5: Hexagonal model of pedagogical content knowledge for science teaching.
From: Park & Oliver, 2008, p. 279.

Model of Domains of Teachers Knowledge and Their Manifestations of Rollnick et al.

Rollnick et al. (2008) consider the PCK an amalgam of four areas of the knowledge base for teaching. They are: a) Content Knowledge; b) Knowledge of Students; c) General Pedagogical Knowledge; d) Context Knowledge. During classroom observations, they concluded that the manifestations of these domains generate other domains or "products of education" (Figure 6). They are: a) Content Representations; b) Instructional Strategies specific for a content; c) Curriculum Saliency; d) Assessment. This model resulted from empirical data with teachers from South Africa in a survey whose aim was to analyze the weight of content knowledge within the pedagogical content knowledge.

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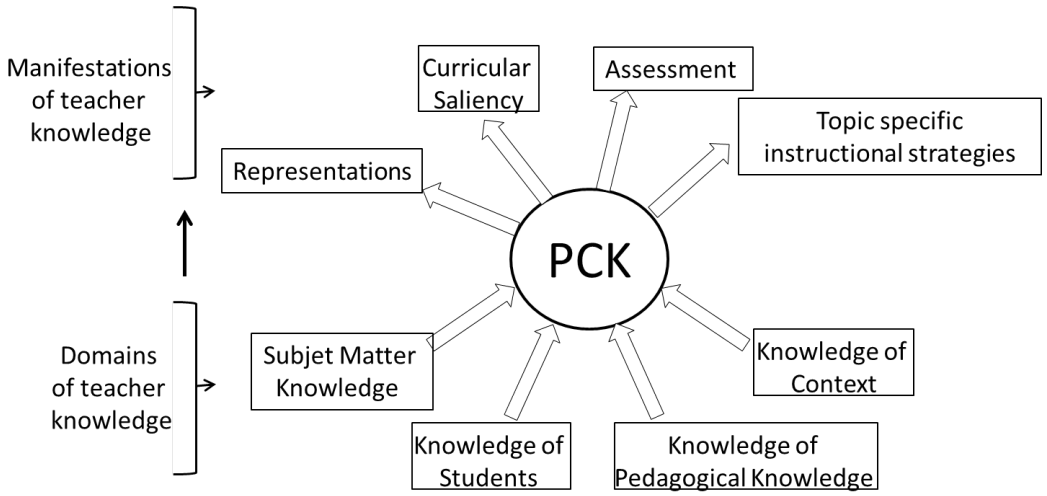

Figure 6: Tailored model for PCK.
From: Rollnick *et al*., 2008, p. 1381.

Morine-Dershimer & Kent's Model and the Emphasis on the Pedagogical Content

Morine-Dershimer and Kent (1999) present a model that shows their interpretation of the place of pedagogical knowledge in respect of all categories of teacher knowledge identified by Shulman (1987) and emphasize three points (Figure 7). One is the close relationship between the aims and purposes and their inseparability from knowledge about assessment processes. Another is that curriculum knowledge is powered by both the content knowledge and the knowledge of goals / assessment processes. And yet in the model only the category knowledge of general contexts is directed to a subcategory of knowledge of specific contexts, but each of the other categories are directly related to pedagogical content knowledge, that means, knowledge of the specific content, knowledge of the specific curriculum and knowledge of objectives / assessment procedures of specific pedagogy and specific students. (Morine-Dershimer & Kent, 1999).

For these authors, therefore, the PCK consists of six knowledge: i) knowledge of the purposes and educational objectives linked directly to knowledge of assessment procedures; ii) pedagogical knowledge; iii) curriculum knowledge; iv) content knowledge; v) knowledge of specific contexts; and vi) knowledge of learners and learning.

Figure 8 shows the conception of Morine-Dershimer and Kent (1999) on the various facets of general pedagogical knowledge that has been reported by recent research on education. Studies on the three main areas that contribute to the general pedagogical knowledge - organization and management of the classroom, instructional models and strategies, communication and discourse in the classroom - have attempted to educational / evaluation processes and goals with students of critical characteristics result from a pedagogical practice, confirming the relationships of Figure 7. It is worth mentioning here the relationship between general pedagogical knowledge, which is the result of research and educational literature and personal pedagogical knowledge that is stocked personal beliefs and practice personal experience. The reflection process promotes the connection between the general and personal pedagogical knowledge so that perceptions formed by personal beliefs and experiences are enhanced and made more objective, while conceptions of pedagogy and principles are exemplified by the research explained and contextualized. The result of this process is the context-specific pedagogical knowledge that helps guide the decisions and actions of teachers (Morine-Dershimer; Kent, 1999).

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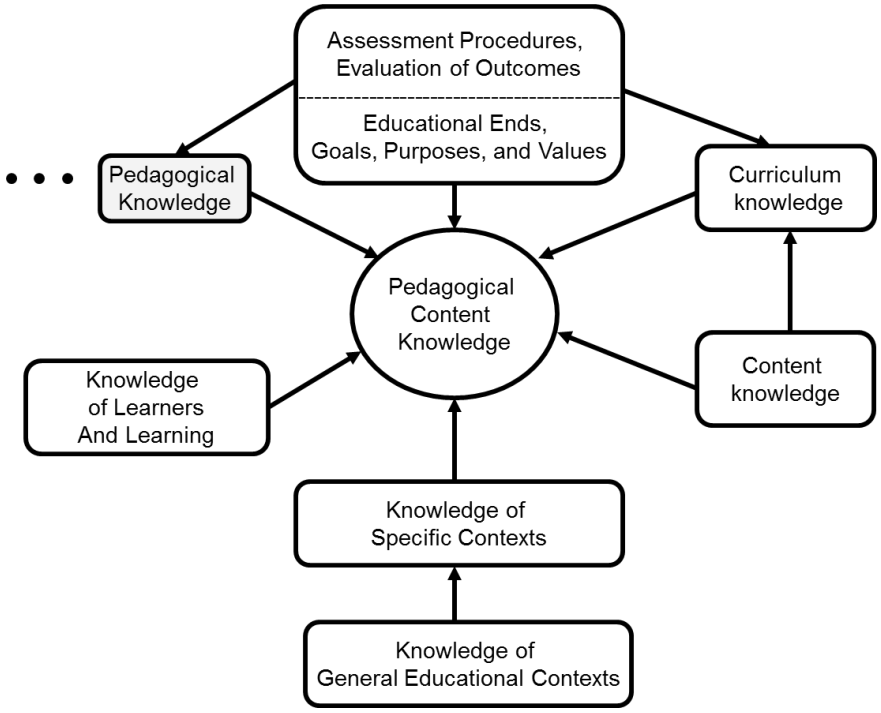

Figure 7: Categories contributing to pedagogical content knowledge.
From: Morine-Dershimer & Kent, 1999, p. 22

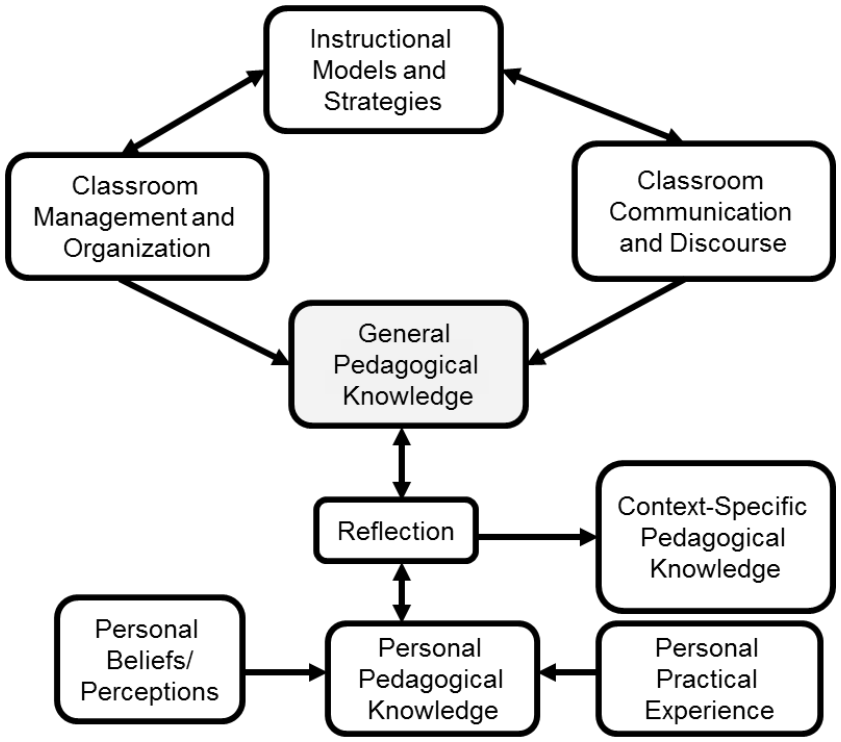

Figure 8: Facets of pedagogical knowledge.
From: Morine-Dershimer & Kent, 1999, p. 23

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Abell's Model – Adding the Knowledge Base of Teachers from Grossman and the PCK Model from Magnusson et al.

In the Handbook of Research on Science Education Abell (2008) proposes a model of teacher knowledge that encompasses the two models most commonly used in the literature: the model of Grossman (1990, figure 2) and the model of Magnusson; Krajcik; & Borko (1999, figure 4) thereby account both components of the knowledge base of teachers and the components of PCK within the same model (Figure 9) that shows so useful.

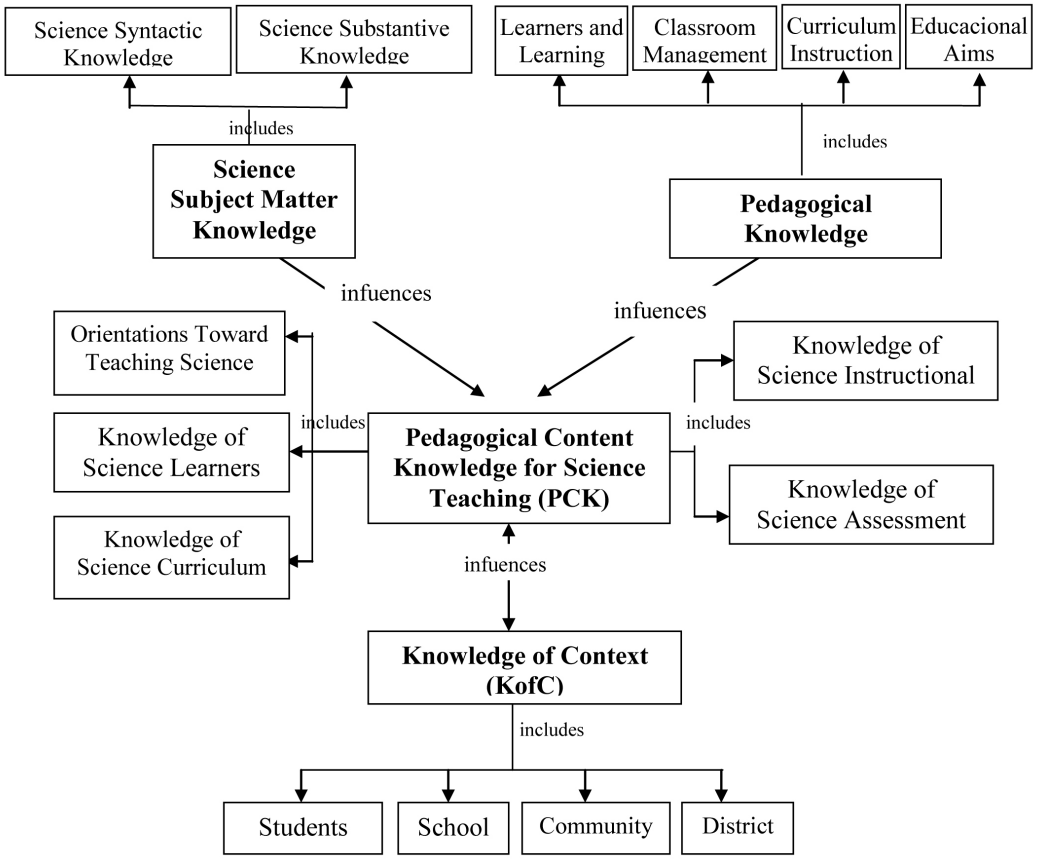

Figure 9: A model of science teacher knowledge (modified from Grossman, 1990 and Magnusson, Krajcik & Borko, 1999).
From: Abell, 2008, p. 1107

Model of the PCK Summit

This is the latest model and is the result of a conference held in 2012, in which thirty researchers met and discussed the PCK, aiming to reach consensus to make the definition of PCK adopted by several groups and an agreed model shown in Figure 10.

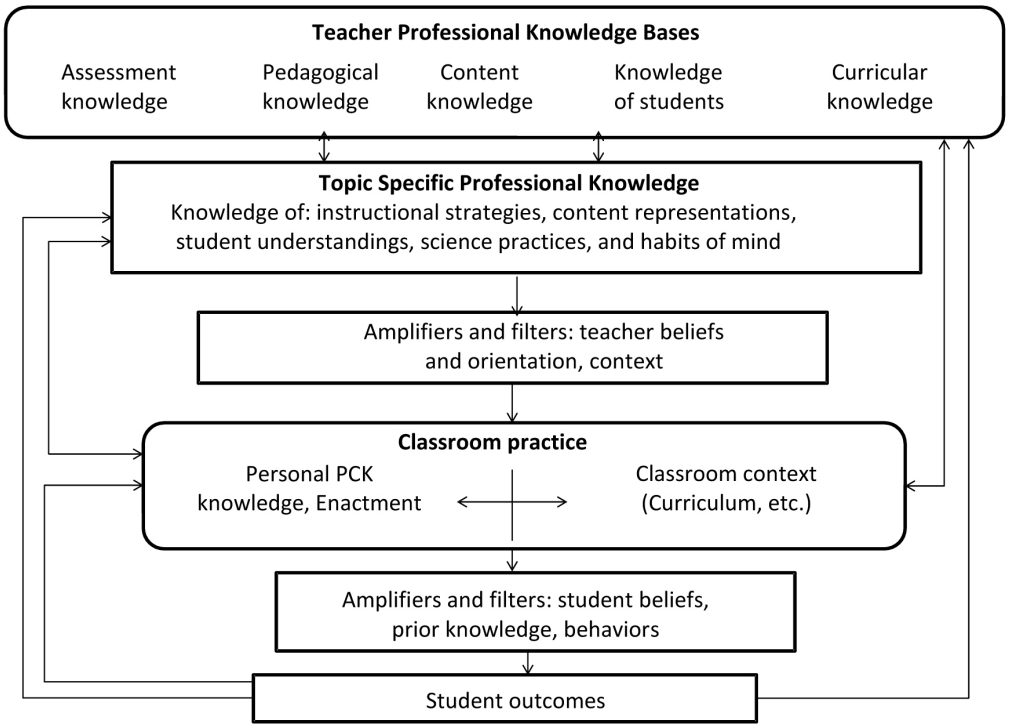

Figure 10: Consensus model of PCK from PCK Summit (Helms & Stokes, 2013; Gess-Newsome & Carlson, 2013).

In the PCK Summit model five main domains are defined for teachers profession: i) knowledge of assessment; ii) pedagogical knowledge; iii) content knowledge; iv) knowledge of students and v.) curricular knowledge. These five knowledge influences and are influenced by the professional knowledge of a particular topic. This professional knowledge includes knowledge of instructional strategies and representations of content, student understanding, scientific practices and habits of mind.

This specific professional knowledge passes through filters and amplifiers, which are the teachers' beliefs, the context in which it is inserted and the orientations for teaching. After this filter, this specific professional knowledge will be transformed and adapted during the classroom practice transforming it in the personal PCK. Then, this knowledge passes through filters and amplifiers of students, taking into account their beliefs, prior knowledge and their behavior, then to be assessed through student outcomes.

In this model seems to have a theoretical PCK (specific professional knowledge of the topic) and a personal, idiosyncratic PCK, which manifests itself in the practice of the classroom, and that this practice influences and is influenced by the knowledge base as by specific professional knowledge of the topic. Student outcomes, in turn, influence both personal PCK from classroom practice and the topic specific professional knowledge as the knowledge base.

It is through this relationship, where the practice of the classroom is influenced and influences the other knowledge that the model is built based on the action, in other words, the teacher is a reflective agent reflecting on their practice and reassesses it to achieve better results with their students reconstructing and transforming your personal PCK, their specific professional knowledge of a topic and its knowledge base. This model reveals both the knowledge being mobilized, but also, as the development of PCK of teachers occurs and dialogues accordingly with the Model Pedagogical Reasoning and Action proposed by Shulman (Figure 1).

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Access, Documentation and Analysis of Science Teachers' PCK

The study of a teacher's PCK is quite complex, because, among other things, to the fact it is a set of implicit knowledge, which should be explained in some way. Thus, various ways have been proposed and evaluated to be sought to document and investigate the PCK of a teacher.

Baxter and Lederman (1999) conducted a compilation of research that sought to access the PCK of science teachers and proposed three groups according to the methodologies used to access the PCK: a) convergent and inferential techniques; b) the representations in the form of conceptual maps, classification and pictorial cards; c) multimethod evaluations. Among the convergent and inferential techniques stand out Likert questionnaires and multiple choice tests. What these methods have in common is the fact that they use verbal descriptions predetermined about the desirable teacher knowledge as a criterion for comparison of the verbal responses of pre-service teachers and teachers. Concept maps have been used to measure knowledge of structures represented by key concepts and the relationships between those terms. In activities with rating cards are requested the teacher to organize the cards in an order that best illustrates the relationships between the items contained in the cards. The use of Likert questionnaires, concept maps and rating cards have been criticized for being too restrictive, because only particular ideas are used and, as a consequence, the results provide just the way the subject sees the ideas presented by the researcher. (Baxter, Lederman, 1999)

In the area of science education, the instruments proposed by Loughran et al. (Loughran, Berry, Mulhall, 2004, 2006, 2008; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001) are very well known. They are named CoRe - Content Representation and PaP-eRs - Pedagogical and Professional experience Repertoires. The CoRe is a tool that proposes research questions about how the teacher selects the contents reflecting on strategies, methodologies and socio-economic and cultural aspects. The PaP-eR is a record of the lesson and reflection of what the teacher believes to be necessary for effective learning.

In studies of PCK, the multimethod assessments are the most used, where a variety of techniques - interviews, concept maps, video stimulated reflection, vignettes and other data collection are used. In the analysis, triangulation of data from these multiple sources is performed and a general profile of teachers' PCK is inferred (Baxter, Lederman, 1999). Examples of research in which this triangulation was used can be seen in recent papers and dissertations (Sales, 2010; Pereira & Fernandez, 2013; Montenegro, 2012; Girotto-Jr & Fernandez, 2013; Oliveira Jr, 2012; Sharma, 2012).

Teacher Education, Development of PCK and the Teacher Education Curriculum

From the foregoing, it is noticed that in view of the recent work the Shulmans ideas have been consolidated. According to Acevedo (2009) each discipline has an educational dimension that is not separated from its contents, by which seems to be essential shift attention from the more generic approaches toward more specific during the training of teachers, which means emphasizing the importance the specific teaching courses in this training (e.g. Methods / Instrumentation for the Teaching of Chemistry).

In an attempt to compile data from the literature, Gess-Newsome (1999) proposes two theoretical models to explain the origin and development of PCK: the *Integrative Model* and *Transformative Model* (Figure 11). The Integrative Model considers PCK as the intersection between the educational, disciplinary and contextual knowledge. The Transformative Model puts PCK as a result of a transformation of pedagogical knowledge, subject matter knowledge and context knowledge (Figure 11).

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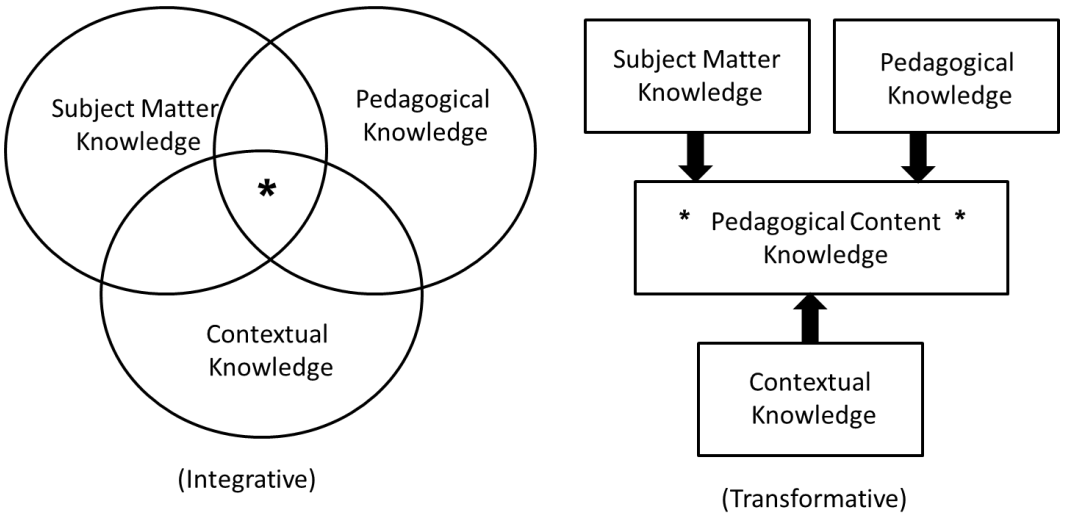

Figure 11: Two models of teacher knowledge (Integrative Model on the left and Transformative Model on the right; * = knowledge needed for classroom teaching.

From: Gess-Newsome, 1999, p. 12.

The two models represent the extremes of a continuum. In the Integrative Model, the PCK does not exist as a domain of knowledge and knowledge of teachers would be explained by the intersection of three constructs – subject matter, pedagogy and context. Teaching based on this view would be the act of integrating knowledge across these three areas (Figure 11). At the other extreme the PCK would be the synthesis of all the knowledge necessary for the teacher education. In this case, the PCK would be the transformation of subject matter knowledge, pedagogy and context knowledge to a distinct way - the only form of knowledge that would impact on teacher practice (Transformative Model, Figure 11).

In Integrative Model knowledge may develop separately and then integrate in the teaching action while the Transformative Model is not so concerned with the development of these skills, but how to become PCK in teaching practice, such as a knowledge base for teaching. The difference between these two models can be explained by an illustrative analogy used by the author. It is the formation of a mixture *vs*. a chemical transformation which result from the act of two chemical substances is placed in contact in the same container. In the case of the mixture, the substances remain chemically distinct, although its visual impact is that of a full integration. The substances of the mixture can however be easily separated by physical methods. On the other hand, in the case of formation of a new product, or as a result of a chemical reaction, the starting substances cannot be separated, and the initial properties cease to exist.

Thus, the Integrative Model would resemble a mixture while the Transformative Model, the initial knowledge base would be fully combined resulting in new knowledge, PCK. The author raises doubts whether the teachers' knowledge would be as of the type of a mixture (Integrative Model) or a compound (Transformative Model). This would bring important implications to research and practice in terms of identifying and developing the teachers' knowledge. Empirical evidence shows, however, that the two models may occur, depending on the professional' moment of the teacher (Kind, 2009).

These models have implications for the curriculum of teacher education. The more traditional training courses for teachers, organized into separate disciplines of content, pedagogy and practice often follow Integrative model of teachers' knowledge. On the other hand, in the transformative model the practice of the classroom must be part of the initial training, as well as case studies and vignettes, among other practical activities.

Therefore, more empirical data are needed at different levels to understand how PCK development occurs and to base public policies on teacher education.

To Nilsson (2008, 2009) both models are a good starting point for analyzing the curricula of teacher education, whether they are experienced teachers or beginners with some experience. These building models of PCK can help teacher educators to plan a curriculum driven to that complete training.

Abell (2007, 2008) believes that science teachers' educators should give explicit attention to the individual components of PCK as a way to aid learning for novice teachers. Barnett and Hodson (2001) argue that experienced teachers have a more accessible, useful and organized knowledge than novice teachers. For them, the beginners "access" knowledge of the concepts, procedures and strategies one by one, while experienced teachers use the most relevant knowledge in an integrated manner. Thus, working with group discussion, where more and less experienced members discuss their own personal beliefs and practices and about the personal practices and beliefs of the other members would each understand the distinct characteristics of the contexts in which they operate. Nilsson (2008) points out that reflection by the pre-service teacher of their professional development becomes him conscious of their own learning. The practice provides experiences for undergraduates, but they also need the discussion of this experience in seminars for their reflection. De Jong, Veal and Van Driel (2002) referring to the formative elements that would help build the PCK of undergraduates reaffirm the importance of incorporating the teaching practice in the training process, along with discussion of articles on educational work, as alternative conceptions of students and how they reason. Nilsson (2008) also notes that the lack of experience of the classroom of undergraduates reflects in their PCK. The author suggests that to stimulate the development of PCK these undergraduates, it is reasonable to recognize the knowledge by parts in order to improve the development of the whole. Rollnick et al. (2008) argue that PCK should be inserted in teacher training, because if you can access the PCK and describe the professional practice of teachers, then it could be transferred to inexperienced teachers, and thus help them in their training.

To Talanquer (2004) the difference between the experienced teacher and the novice teacher is, for example, in the fact that when choosing an activity, the novice teacher selects a book and follows the sequence proposed by the author. On the other hand the experienced teacher has a "look" for the book completely differently. According to the author, "[...] the task demands that teachers reflect on the goals, purposes and philosophy of what to do in chemistry in a given context – considering the level of intellectual development, prior knowledge, interest and motivations of their students".

According to Talanquer (2004), teacher training programs should collaborate to build the PCK of future teachers, opening spaces for the key pieces of the content to be taught are subject to analysis and didactic and pedagogical discussion. [...] This type of reflection would help student teachers develop their PCK as well as the critical capacity and analytical skills that allow them to design the classroom as a space exploration and continuing research.

Like other disciplines, chemistry has its particularities that require consideration by the teacher in the classroom. The teaching of science has documented a repertoire of students' difficulties in certain content. The chemistry experienced teacher need to consider these difficulties in planning their teaching and adjust the chemical content to their students in a given context. For example, in balancing a chemical equation the novice teacher pays little attention to the type of problem used. In turn, the experienced teacher will make a careful selection, so that his/her sequence presents examples of combinations of chemicals that exist in atomic and molecular form, problems where there is an exchange of polyatomic ions, examples working balance of mass and charge, etc. The experienced teacher will recognize the difficulty of students to understand why the number of atoms, but not the molecules is conserved during a chemical reaction and will be aware of this difficulty, selecting examples that put those ideas into conflict. Anyway, just analyzing the decisions that a chemistry teacher takes in his/her classroom to be able to recognize the nature and complexity of PCK that his/her work demands. Such

decisions are anchored in a content knowledge impregnated pedagogically that is embedded in the teacher initial education and expanded substantially in their experience of the classroom. (Talanquer 2004)

Final Considerations

Based on this brief overview of the literature on PCK and on their development, is it possible to observe some differences, but is also explicit its importance in terms of research to understand the professional development of teachers. Once the PCK includes several key elements of the knowledge of teachers, it is the central model whose study is able to provide support for curriculum reforms in teacher education.

There is evidence that the PCK is a fruitful model that contributes to the understanding of the professional knowledge of teachers, systematizing empirical data and enables the documentation and exchange of ideas on relevant knowledge to teaching practice. It is a complex concept, since it arises from various human interactions in different contexts.

In a relatively recent review article on the PCK Kind (2009) lists the different approaches to understanding the PCK and points to two basic differences in the conceptions of the authors in relation to the position of content knowledge, namely: i.) the knowledge of content is a knowledge base of teachers but would not be part of PCK; ii.) the content knowledge is part of what is called pedagogical content knowledge. In the original proposal of Shulman (1987), content knowledge was not included in PCK, but it was one of the seven basic knowledge of teachers. The models of Grossman (1990), Magnusson, Kracjik & Borko (1999), Carlsen (1999), Abell (2008) and the model of PCK summit follow that line, leaving the content knowledge external to PCK and belonging to base knowledge. Other proposals differ from the original idea of Shulman, incorporating content knowledge to PCK (Fernandez-Balboa, Stiehl, 1995; Koballa, Gräber, Coleman, Kemp, 1999; Marks, 1990; Cochran, DeRuiter, King, 1993; Veal, Makinster, 1999; Banks, Leach, Moon, 2005).

The PCK model originally presented by Shulman included content representations, students' difficulties and instructional strategies. In addition, the Shulmans' model was already highlighted the reflection process in the development of PCK. After Shulman models differ as to what knowledge should be included in PCK and which should list the knowledge base.

As already mentioned above, a first distinction between the models refers to the fact that content knowledge is part of the knowledge base or part of PCK. A second distinction is the inclusion of the knowledge of the assessment and if it is part of the base or part of the PCK. Initial models from Shulman and Grossman didn´t considered knowledge of assessment as a separated component. So, in this case, Magnusson Kracjik & Borko (1999) made a good contribution including this component. After these authors, other models consider assessment knowledge as an important component, even though they differed if is a component of the base knowledge or of the PCK.

Some models, starting from the idea of Grossman, emphasize the role of context (Carlsen, 1999), others emphasize the pedagogical knowledge (Morine-Dershimer & Kent, 1999).

The model of the PCK summit somehow revisits the initial model from Shulman's both in terms of PCK and in terms of base knowledge and incorporates new elements that were brought by other models presented. In the PCK summit model, the assessment knowledge, which had been ignored by Shulman and Grossman, is incorporated into the knowledge base. In addition to this knowledge, appears as a base knowledge, agreeing with the initial idea Shulman, the knowledge of the curriculum (separate from pedagogical knowledge like in Grossman's model) and knowledge of students (separate from context as in Grossmans'). The PCK summit model still represents the development of PCK with the practice in the classroom and incorporates the role of the beliefs of teachers and students, while also taking into account the filter of the context. Thus reaffirms the initial idea of Shulman and Grossman and replaces PCK again in the center of the knowledge base of teachers. For these reasons the model of the PCK

summit seems a improved model compared to other models by incorporating elements of previous models and have made a remake of the original idea of Shulman and Grossman.

Regardless of the different interpretations, PCK currently has been considered the best theoretical framework to examine and understand the skills of teachers, systematizing empirical data and enables the documentation and exchange of ideas on relevant knowledge to teaching practice (Fernandez, 2013). Thus, the study of PCK of teachers in different professional moments (initial training, trainees, beginners, experienced, pre- and in-service training, etc.) aims to provide bases for the training of teachers. If the professional practice of good teachers can be accessed and documented, can then be used as a starting point for inexperienced teachers and thus help them in their training. There is consensus that the training courses for teachers should have as an explicit goal the development of teachers' PCK. His documentation and exploitation during the initial training can assist undergraduates in the process of becoming better teachers as well as to assist experienced teachers to develop more reflective practices and thereby promote further development of their PCK. Thus, the central role of the reflective process in the development of PCK should be a point to be considered in curriculum reform as well as the potential the PCK concept has for informing science teacher education.

But, on the other hand, since there are different ways of conceptualizing PCK and different authors propose different models in which some skills are prioritized over others, it is important to be aware and present which model is being used in research related to PCK. The lack of information may bring difficulties to the reader and can increase the amount of criticism that has been made to this concept.

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