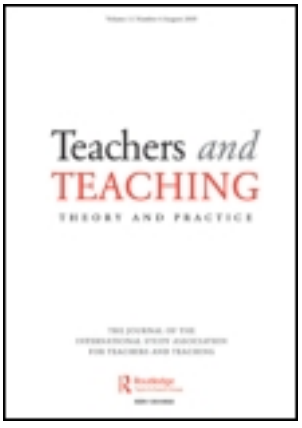

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Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge

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A brief review of the history of pedagogical content knowledge reveals various definitions and conceptualizations of the construct, as well as some conceptual problems. A new conceptualization—teacher pedagogical constructions—is offered to address some of the problems associated with PCK. Seven assertions that comprise the new conceptualization are presented, explained and defended. These are: (1) PCK represents personal and private knowledge; (2) PCK is a collection of basic units called teacher pedagogical constructions; (3) teacher pedagogical constructions result mainly from planning, but also from the interactive and post-active phases of teaching; (4) pedagogical constructions result from an inventive process that is influenced by the interaction of knowledge and beliefs from different categories; (5) pedagogical constructions constitute both a generalized event-based and a story-based kind of memory; (6) pedagogical constructions are topic specific; and (7) pedagogical constructions are (or should ideally be) labeled in multiple interesting ways that connect them to other categories and subcategories of teacher knowledge and beliefs. The proposed definition results from a reconceptualization of the nature of PCK as originally proposed, taking the results of major later studies and conceptualizations of PCK into consideration, appropriating new ideas about the structure of memory, and undertaking a reanalysis and presentation of data from a previous study. The article calls for viewing PCK as neither a subcategory of subject matter (subject matter knowledge for teaching) nor as a general generic form of knowledge. It presents a view of PCK as a collection of teacher professional constructions, as a form of knowledge that preserves the planning and wisdom of practice that the teacher acquires when repeatedly teaching a certain topic. Viewing PCK as a collection of TPCs, more precisely defining it, clarifying its relations to other knowledge and beliefs entities, and speculating about its development should facilitate future investigations of PCK.

Keywords: *Teacher knowledge; Teacher beliefs; Pedagogical content knowledge*

Introduction

> It is this belief in the value-laden nature of subject matter, teaching, learning and school practices that provides the foundation of understanding the narrative nature of pedagogi-

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> cal content knowledge. Values and narratives are inexorably intertwined. Together they have one fundamental principle in common. This basic principle is that narratives help us understand the world. (Gudmundsdottir, 1995, p. 28)

This quotation, taken from a chapter written by Sigrun in 1995 entitled 'The narrative nature of pedagogical content knowledge' exemplifies the development of her thinking about pedagogical content knowledge. PCK has both values and narrative components. In an article written five year earlier (Gudmundsdottir, 1990), Sigrun had emphasized the values component of PCK:

> In this article I give expression to the voices of four excellent experienced high school teachers and demonstrate how their values cement pedagogy and content to create their practical and powerful pedagogical content knowledge. (p. 45)

The teachers she described had created pedagogical models that reflected each teacher's values and his or her orientation to the discipline.

This conception of pedagogical content knowledge as having a component related to the teacher's beliefs about content or subject matter was not unique to Gudmundsdottir. Shulman and his colleagues were already pointing out this component (see, for example, Grossman *et al.*, 1989). However the distinctive contribution of Sigrun was her insistence on both the value-laden and narrative nature of PCK.

In the meantime other researchers and scholars were proposing additional components of PCK. It had been transformed from that special amalgam of subject matter and pedagogy that Shulman (1986a, 1987) described to a category of teacher knowledge that curiously seemed able to encompass all other categories of teacher knowledge and beliefs—such as knowledge of subject matter, orientations, student characteristics, aims and purposes, resources and pedagogy. Additionally, PCK seemed to have lost one of its most important characteristics, its topic specificity, and was being thought of as a broad and general form of knowledge (one article, by Fernandez-Balboa & Stieh, 1995, was entitled 'The generic nature of pedagogical content knowledge among college professors'). If PCK, according to some researchers, has become that generic all-encompassing form of teacher knowledge and beliefs then we do not need the term PCK—it has become synonymous with teacher knowledge and beliefs, and even practices for some. On the other hand, many researchers have empirically examined teacher PCK and concluded it includes some or all of these components. It seems we have reached an impasse regarding the nature of PCK and its utility as a theoretical construct. In this article I suggest that this is not the case. If we examine the original conceptualization of PCK, and accept a more precise definition of the term, taking Gudmundsdottir's contention about its beliefs-ladenness and narrative nature into consideration, we can move forward. Additionally, I propose a model that describes the interrelations between PCK and other categories of teacher knowledge and beliefs, and that serves to explicate its nature and development. I propose a new term for pedagogical content knowledge, teacher pedagogical constructions (TPCs), that better conveys the meaning and development of PCK. I use empirical support, when needed, mainly from the initial study that identified PCK (Hashweh, 1985).

What is pedagogical content knowledge, and how does it develop?

In his two seminal articles Shulman (1986a, 1987) presented and explicated the construct of pedagogical content knowledge. The 1986 article was mainly involved with teacher knowledge of subject matter, the missing paradigm that Shulman identified in another article in the same year (Shulman, 1986b). Consequently, pedagogical content knowledge was introduced as a subcategory of teacher content knowledge (the two other subcategories being subject matter content knowledge and curricular knowledge):

> A second type of content knowledge is pedagogical knowledge, 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. (p. 9)

Shulman went on to point out that this knowledge, associated with 'the most regularly taught topics in one's subject area' (p. 9), includes representations of knowledge (analogies, illustrations, examples, explanations and demonstrations), and student learning difficulties and strategies to deal with them.

According to this conceptualization, PCK (1) was a subcategory of content knowledge; (2) is topic-specific; and 3) included two further subcategories: knowledge of representations and of learning difficulties and strategies for overcoming them. While the topic-specificity of PCK was neglected by some researchers, the conceptualization of PCK as a subcategory of teacher content knowledge (as subject matter knowledge for teaching) was accepted. Shulman's emphasis on the transformation of subject matter for teaching (knowledge of representations) obscured for many researchers the other component: knowledge of student difficulties and related teaching strategies. Moreover, to my knowledge, no one raised the question of how knowledge of student learning difficulties and of strategies to overcome these difficulties could be classified as a subcategory of content knowledge. In other words, educators accepted a conceptualization of PCK as an amalgam of content knowledge and pedagogy and also as a component of content knowledge.

In the 1987 article Shulman identified PCK as a category of the knowledge base of teachers, as one of seven categories that also included content knowledge, general pedagogical knowledge, curriculum knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes and values. PCK was conceptualized here as a category on its own, and not as a subcategory of content knowledge as conceptualized in the 1986 article. Clearly the conceptualization of the construct needed further development.

In this second article, Shulman again emphasized the topic specificity of PCK, and, implicitly, how it develops as a result of interactions among different components—or categories—of teacher knowledge and beliefs:

> By focusing on the teaching of particular topics—*Huck Finn*, quadratic equations, the Indian subcontinent, photosynthesis—we learned how particular kinds of content knowledge and pedagogical strategies necessarily interacted in the minds of the teachers. (p. 5)

However, by proposing PCK as one out of seven categories of the knowledge base, and by neglecting the interactions among these categories, the hierarchies that might exist between them, or the different forms or types of knowledge in each category, Shulman left the task of further developing the conceptualization of PCK to others. At a time when inquiry into teacher knowledge and beliefs was in its infancy this was a very important contribution. During the ensuing 20 years we witnessed different developments in the conceptualization of PCK.

It is not necessary for our purposes to attempt to comprehensively trace the developments in conceptualizations of PCK. It is enough to provide examples to identify some major trends. The first trend was to include new knowledge and beliefs components as subcategories of PCK. Grossman (1990) added two other components to PCK (in addition to the two identified by Shulman—representations and student difficulties with topic): knowledge and beliefs about purposes, and knowledge of curriculum materials—components that had been considered by Shulman as separate categories of the knowledge base. Here we notice early inclusions of what were considered as categories separate from PCK into PCK itself. Marks (1990) included knowledge of subject matter per se as part of PCK, while neglecting Grossman's inclusion of purposes. Closely related to this trend was the tendency of some researchers to view PCK as a category of teacher knowledge and beliefs that is not different in type from other categories, for example, in treating PCK as general theoretical knowledge just like subject matter knowledge.

Another approach (though, because limited to a few researchers, it cannot properly be termed a trend) was to emphasize the influence of other categories of teacher knowledge and beliefs on PCK. An important contribution was made by Cochran *et al.* (1993) when they emphasized that PCKg (pedagogical content knowing) is the:

> … teacher's integrated understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning. (p. 266)

Fernandez-Balboa and Stieh (1995), while claiming that PCK had a generic nature, also asserted that PCK results from the integration of different knowledge components. In contrast to the claim about the generic nature of PCK, van Driel *et al.* (1998) emphasized the topic specificity of PCK: 'In our view, the value of PCK lies essentially in its relation with specific topics' (p. 691). Finally, a conceptualization of PCK that captures both its topic-specificity and its development as a result of interactions between other knowledge and beliefs categories was presented by Loughran *et al.* (2001).

If we return to examine the first study that identified pedagogical content knowledge (there termed subject matter pedagogical knowledge) (Hashweh, 1985), we find it conceptualized PCK as the topic-specific knowledge that the teacher develops and accumulates in relation to teaching that topic. It included the topic-specific student alternative conceptions which students bring with them and how to engage these student prior ideas, the specific student difficulties and how to deal with them, and the specific knowledge representations which the teacher uses—the knowledge representations, the student characteristics, and the pedagogy subcategories that Shulman and others discussed. It included other subcategories as well: levels of treatment of a

topic, student specific prior knowledge, and aims and purposes (termed utility of the topic in that study). In a prior chapter on subject matter knowledge, the study showed how the teacher's approach or orientation to his or her discipline (for example, molecular, ecological or evolutionary approaches for the biology teacher) influences the teaching of a certain topic, but this was not included as a subcategory of PCK. The original conceptualization, therefore, included six subcategories, emphasized the topic specificity of PCK and speculated about its development. However, in a later chapter of the same study, Hashweh categorized PCK as a subcategory of subject matter knowledge, probably influencing later conceptualizations, and affecting the later neglect of many subcategories of PCK. However, almost 20 years later, we find that conceptualizations of PCK are closer to the original conceptualization.

This being said, and as previously pointed out, these trends do not converge on a clear conceptualization of PCK. Indeed they portray differences of opinion, and lack of clarity, about the nature of PCK and its development. They raise questions about the components of PCK, the type of knowledge it represents, its generality or specificity, and its development. The following definition of PCK attempts to redress this situation. The proposed definition results from a reconceptualization of the nature of PCK as originally proposed in Hashweh (1985) and Shulman (1986a, 1987), taking the results of major later studies and conceptualizations of PCK into consideration, appropriating new ideas about the structure of memory (Schank, 2000), and undertaking a reanalysis and presentation of the data in a previous study (Hashweh, 1985).

> Pedagogical content knowledge is the set or repertoire of private and personal content-specific general event-based as well as story-based pedagogical constructions that the experienced teacher has developed as a result of repeated planning and teaching of, and reflection on the teaching of, the most regularly taught topics.

The following assertions are incorporated in this definition:

1. PCK represents personal and private knowledge.
2. PCK is a collection of basic units called teacher pedagogical constructions.
3. Teacher pedagogical constructions result mainly from planning, but also from the interactive and post-active phases of teaching.
4. Pedagogical constructions result from an inventive process that is influenced by the interaction of knowledge and beliefs from different categories.
5. Pedagogical constructions constitute both a generalized event-based and a story-based kind of memory.
6. Pedagogical constructions are topic specific.
7. Pedagogical constructions are (or ideally should be) labeled in multiple interesting ways that connect them to other categories and subcategories of teacher knowledge and beliefs.

Private knowledge

The definition indicates, firstly, that what we are studying here is personal and private knowledge, rather than public and objective knowledge. We capture this knowledge

by observing individual teachers at work and talking to them. We ask them to plan while thinking aloud, or ask them how they would respond to certain critical incidents that might occur in teaching a certain topic (see Hashweh, 1985). Efforts by some researchers to capture and represent PCK, as well as teacher self-reports, cases and teacher research, can transform it into more public knowledge.

PCK as a collection of teacher pedagogical constructions

Secondly, the definition asserts that PCK is a group or collection of smaller knowledge entities or units that I called pedagogical constructions. The plural term 'constructions' better indicates the conceptualization of PCK as a set of entities and not as one whole unit. To use an analogy from chemistry, each of these constructions is a molecule, but PCK is essentially a mixture of different molecules, and not a new compound (larger and more complex molecules). This is in contrast to the deep knowledge that a teacher might have of subject matter, where the knowledge is well organized and hierarchically ordered.

Teacher pedagogical constructions develop through experience

Thirdly, these units are teacher intellectual and professional constructions. They comprise the knowledge that the experienced teacher builds and accumulates pertaining to the teaching of specific regularly taught topics, such as photosynthesis for the science teacher. I claim that they result initially, and most importantly, from teacher planning, which is essentially a design process (Yinger, 1977). When a teacher plans for teaching a topic, such as photosynthesis, he or she has to answer different questions.

- What level of details and understanding do I expect/aim to accomplish when I teach it to eighth-graders?
- How can I utilize the topic to emphasize important ideas in biology?
- What other ideas can I relate it to?
- What other ideas in higher grades will build on what I am teaching now?
- What are the student difficulties and alternative conceptions that might be present, and how do I engage these prior knowledge and understandings?
- What representations of knowledge (analogies such as the factory and the leaf, examples, demonstrations, activities) can I use?
- How do I assess student understanding of this topic?

The teacher draws on many sources of knowledge for answering such questions. The most important of these sources are the other general categories of teacher knowledge and beliefs—knowledge of subject matter, of students, pedagogy, assessment and other categories. The resulting plan, whether mental or written, is a construction, not as tangible as the end-product of an architectural design process, but a construction none the less. Lately, many educators have accepted constructivism as an orientation, and have described learning as a constructivist process. If anything among all teacher knowledge categories is truly constructed, it is definitely the PCK category. Of

course, these constructions are further developed as a result of interactive teaching and post-active reflection. A teacher might invent an analogy during interactive teaching when she realizes she needs one more representation to explain a certain concept. Or she might, upon reflecting on the last period, realize she needs a new analogy, and invents a new one or asks a more experienced colleague. These analogies are added to that teacher's pedagogical construction. If we develop the architectural design analogy further, these pedagogical constructions embody the implemented building, not just its plans. Finally, if we perceive pedagogical constructions as resulting from a design process, as solutions to ill-structured problems, we realize that diversity is a natural outcome—different teachers will come up with different inventive solutions to the problem of teaching a certain topic at a certain grade level.

We should stress, before leaving this point, that PCK is knowledge associated with experience, and does not seem to develop from studying in pre-service teacher education programs, at least the traditional ones. In Hashweh's study (1985), three physics and three biology teachers were asked to plan to teach two topics, photosynthesis and simple machines. As a result, each teacher planned to teach one topic which was within his or her field of expertise, and with which he had experience in teaching, and another topic which was new to him or her. The experienced teachers, in most cases, did not do much planning, but seemed to recall their previous knowledge in teaching the topic. The inexperienced teachers had to do more actual planning and make up analogies, examples, or demonstrations to use in teaching.

Pedagogical constructions are influenced by the interaction of different knowledge and beliefs categories

Fourthly, and as mentioned above, the pedagogical constructions are largely the result of the interaction between different teacher knowledge and beliefs categories. Rich PCK does not result from deep knowledge in a single knowledge category. For instance, subject matter knowledge alone is not enough. Teachers who are able to detect student alternative conceptions in photosynthesis, and who have developed superior strategies for engaging these student prior ideas, are not only knowledgeable about photosynthesis; they also hold constructivist epistemological beliefs (Hashweh, 1985). Gudmundsdottir (1990) was right: PCK has a value or beliefs components but it also has a subject matter component, a purposes component, a pedagogy component and other components. Teachers develop what some have called an amalgam of subject matter knowledge and pedagogy, and other categories as well, to teach particular topics. To pursue our chemical analogy further, each new pedagogical construction is a newly designed compound, a new molecule, that the teacher has designed using atoms from different elements at his or her disposal (the categories of knowledge and beliefs such as subject matter knowledge, general pedagogy, educational aims and purposes, etc). As a result, it is not surprising that upon careful analysis we are able to identify the different original atoms in this new compound. This explains why researchers felt obliged to include in PCK some knowledge categories that others have conceptualized as separate knowledge categories. However, PCK is not part of other

knowledge and beliefs categories, and certainly not a subset of the subject matter knowledge category. There is even an indication that teachers themselves are cognizant of the difference. When one teacher was asked about what she knew about photosynthesis she gave a very detailed account of her subject matter knowledge. The researcher then asked if she could add more details, and she gave a detailed account of the knowledge associated with teaching photosynthesis (Hashweh, 1985).

Research on teacher planning flourished in the late-seventies and eighties (Clark & Peterson, 1986). It showed, among other things, that teacher planning is a non-linear design process that usually starts with a teacher thinking about subject matter, moves to teaching methodology, and then takes other factors into consideration. However, the models that were developed to describe teacher planning focused on processes and neglected content. In my teaching of planning in a pre-service teacher education program at my own institution I use the framework presented in Figure 1 to help prospective teachers plan. It is a model that assumes that planning is a design process which is cyclical and interactive in nature. Although this is a normative model of teacher planning it is interesting that it includes many of the different categories of teacher knowledge and beliefs interacting to produce a teaching/learning activity (a pedagogical construction?).

It is interesting to note that in our efforts to understand teacher knowledge and thinking we have focused on knowledge at the expense of thinking processes. An examination of the last two handbooks of research on teaching is revealing. The third edition of the *Handbook of research on teaching* (Wittrock, 1986) had the first part dedicated to theory and methods, and the second to research on teaching and teachers. The first

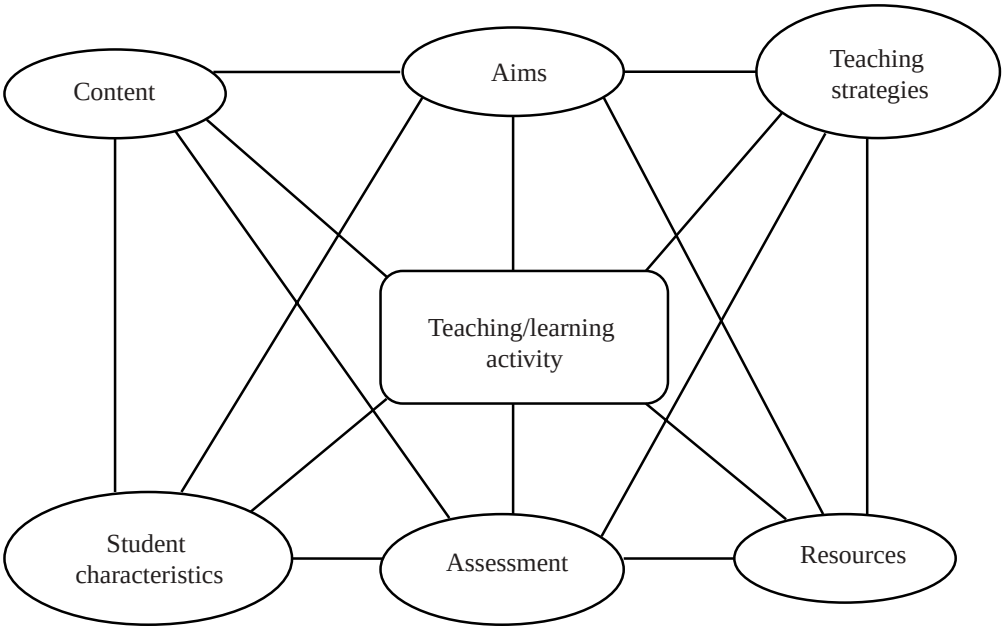

Figure 1.

chapter in the second part was dedicated to research on teachers' thought processes, with very little emphasis in it on teacher knowledge and beliefs. Research on the teaching of the different subject matters was left to the final, fifth part of the book. In the fourth edition (Richardson, 2001) the teaching of subject matter has moved to part 3 (theory and methods now took the first two parts rather than one), while research on teachers and teaching has been moved to part 6. Two chapters in this part are dedicated to teacher knowledge and teacher change, and no chapter deals with teachers thought processes. Shulman's missing paradigm (1986b) is certainly very visible now. But have we focused on knowledge too far? I think that the answer is yes. To understand what PCK really is we need to devote attention to its development, and studying teacher planning again, given the arsenal of theoretical and methodological tools that we now possess, might be a fruitful program. In this respect it is worth mentioning that the first study to identify PCK was a study that investigated teacher planning and simulated interactive teaching (Hashweh, 1985).

The teacher planning literature of two decades ago focused on processes and neglected content. It was mainly concerned with elementary school teachers. Recently, there has been some renewed interest in the study of teacher planning. A recent study paid attention to subject matter knowledge and PCK in the planning of a secondary school teacher (McCutcheon & Milner, 2002). It showed that the teacher drew on his rich content knowledge in long-term pre-active planning to develop interconnected themes for his courses, and that this kind of planning was his major form of planning. In another study (Milner, 2003) it was found that PCK was involved as a base for teacher planning, but the study failed to study the development of PCK as a result of planning. Both studies call for a renewed interest in teacher planning. On the other hand, research on PCK had failed to examine teacher planning. The time is appropriate for a renewed study of teacher planning, with an emphasis on the dialectical relations between teacher knowledge and beliefs and teacher planning. Of course, PCK is the most interesting among knowledge and beliefs to study.

To further clarify the assertion that pedagogical constructions result mainly from the interactions between different kinds, or categories, of teacher knowledge, and that they contain the traces of these original knowledge categories, Figures 2, 3 and 4 show a model of a hypothetical science teacher's knowledge and beliefs. I use the term 'hypothetical' because, although the model was partly inductively built using a reanalysis of the data from one of the six teachers studied in 1985 (Hashweh, 1985), the model is partly speculative because the original study did not aim to describe the full range of teacher knowledge and beliefs of the teacher. Its aim was to describe some categories, mainly teacher knowledge of subject matter, and teacher conceptions of learning and their effects on teaching. Consequently, in Figure 3 I hypothesized the existence of some general knowledge categories, such as knowledge of resources or knowledge of context, and developed the model proposed in an earlier study (Hashweh, 1985, pp. 329–330), using Shulman's (1986a, b, 1987) conceptualizations and those of some of his students and colleagues. As a result, the model of teacher knowledge and beliefs, and of pedagogical content knowledge in particular, that is presented in this study, while partly supported by Hashweh (1985) and

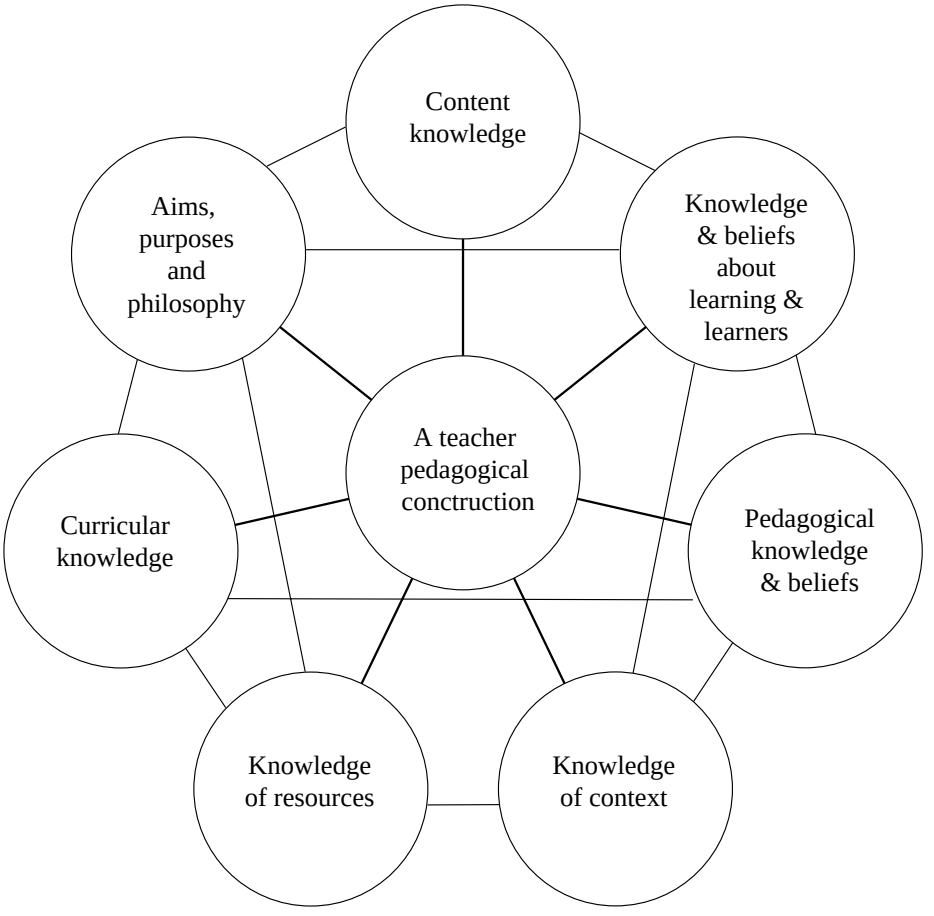

Figure 2.

consonant with studies of teacher knowledge and PCK, emphasizes the hypothesis-formation phase of educational inquiry, and should be more formally tested in the future.

The lines in Figure 2 represent some of the possible interactions between the different knowledge categories, and the dialectical relationships between PCK, or TPCs in particular, and the different knowledge categories. Figure 2 should be viewed as a snapshot of the teacher's 'conceptual ecology' (Strike & Posner, 1992) at a certain point in time. While the Figure shows the interactionist view of these ecologies, it fails to show the developmental view of the ecologies. A TPC has a niche in a certain conceptual ecology; it is part of a web of interacting intellectual entities. While we have emphasized how the context or ecology affects the TPC, the TPC itself also affects the ecology. A teacher who has developed, perhaps implicitly, one or more TPCs that include anomalies to confront student misconceptions (in the photosynthesis and respiration TPCs, for example) may upon reflection on her practice generalize the strategy and store it as an explicit strategy in her general pedagogical

Science teacher knowledge and beliefs

Subject matter knowledge and beliefs
- Substantive knowledge
  - Knowledge of concepts, principles, relations, topics
  - Knowledge of higher-order principles or conceptual schemes (e.g., energy storage and release in chemical reactions)
  - Knowledge of approaches, or of different ways of relating topics to other discipline 'entities' (concepts, principles, topics, conceptual schemes) (e.g., a molecular/energy approach to biology)
- Syntactic knowledge
  - Knowledge of science process (control of variables, etc) and scientific inquiry (identification of a problem, testing hypotheses …)

Aims, purposes and philosophy of education
- Beliefs about general aims of educations (e.g., biology can be taught to develop good nutritional habits or to develop environmental awareness)
- Beliefs about aims of science education

Knowledge and beliefs about learning and learners
- Conceptions of learning (e.g., social constructivist beliefs)
- Knowledge of student characteristics (experiences, abilities, interests …)

Pedagogical knowledge and beliefs
- Beliefs about importance of representations
- Knowledge of general lesson types (developmental lesson, lecture, demonstrations, laboratory, group work, …)
- Knowledge of planning
- Knowledge of classroom management

Curricular knowledge
- Vertical curricular knowledge (science curriculum in different grade levels)
- Horizontal curricular knowledge (curricula of different subjects in same grade level)

Knowledge of resources
- Knowledge of available textbooks, films, equipment, etc …

Knowledge of context
- Knowledge of local educational system
- Knowledge of community
- Knowledge of particular students

Pedagogical content knowledge (see separate frame)

Figure 3.

knowledge category. Strike and Posner, though discussing conceptual change in science students rather than teacher knowledge, expressed it well:

> Our view … must therefore be more dynamic and developmental, emphasizing the shifting patterns of mutual influence between the various components of an evolving conceptual ecology. We must say with Heraclitus that all is in flux. … [I]t is difficult to step into the same conceptual ecology twice. (p. 163)

Examination of Figures 3 and 4 reveals how components of the general knowledge categories are echoed, at a more concrete or in a more local level, in the TPCs. As previously mentioned, each of the two frames displays parts of the knowledge of a hypothetical biology teacher, based on the findings in Hashweh (1985). The data that was used in these two frames comes from biology teacher BA, one of three biology

Pedagogical content knowledge

Photosynthesis pedagogical construction

Subject matter

Knowledge of photosynthesis details (input, output, dark and light cycles …)

Potential energy is stored in bonds in glucose molecules that are produced by photosynthesis

Photosynthesis and respiration are related: the energy that is stored in the molecules in photosynthesis is released when these molecules are broken down in respiration

Aims/purposes

Relate photosynthesis to respiration, and use respiration to discuss nutritional value of breakfast for students

Relate photosynthesis to production of oxygen by plankton in seas, and discuss effects of pollution

Student characteristics

Students think plants take their food from soil, that plants respire only at night, and photosynthesize only during the day

Students do not know enough chemistry to understand photosynthesis

Students have difficulties in understanding how ATP-ADP transformations occur, and the function of ATP in energy transfer

Teaching photosynthesis

Lesson types

Developmental lesson on first day to teach …

Laboratory on second

Worksheets, followed by revision and mini-lecture on third, etc…

Explanations, representations and teaching Strategies

To emphasize that oxygen from photosynthesis comes mainly form the sea I use a film and the example of oxygen in the desert

To explain ATP I use the shopping cart or the paper bag analogy

To confront misconception of respiration only at night I show need for energy all the time

Activities and assignments

Activity of water plant to measure amount of oxygen produced by photosynthesis

Examining Elodea cells under the microscope

Assessment

Questions that I use to assess understanding of function of photosynthesis, or to detect if they still believe plants take their food from soil

Different versions of end-of-unit exam that I use

Curriculum

Relate to a previous unit on structure and function

Prepare for a future unit on respiration

Resources

Knowledge of particular film about photosynthesis

Handouts and worksheets I have previously developed about different aspect of photosynthesis

Context

Should finish this unit in two weeks

Student X can bring Elodea plant

Can relate this to study of local ecology

Respiration pedagogical construction

Structure and function pedagogical construction

Figure 4.

teachers and three physics teachers who were studied. Each of the teachers was interviewed to assess his/her knowledge of subject matter (one physics and one biology topic) using summary free recall, concept-map line labeling, and sorting tasks. The teachers' conceptions of learning were assessed using the clinical interview method.

Each teacher's planning and simulated teaching of each of the two topics were assessed using think-aloud and critical-incidents techniques. Relations between some general knowledge categories, presented in Figure 3, and some subcategories of the Photosynthesis TPC, presented in Figure 4, will be illustrated below using biology teacher BA's data.

Figure 4 gives some details of the Photosynthesis TPC, but it should be realized that PCK contains other TPCs, such as the Respiration TPC and the Structure and Function TPC. As can be seen, the Subject Knowledge and Beliefs category (Figure 3) is echoed in the Photosynthesis TPC (Figure 4). The teacher has a molecular/energy approach or orientation to her subject matter (it might be remembered that the BSCS produced three versions of their curriculum: molecular, ecological and evolutionary versions). When assessing this teacher's knowledge of subject matter she emphasized the chemical and energy-related aspects of biological processes at the cellular level. This teacher's approach is reflected in her teaching of photosynthesis: she relates photosynthesis and respiration to emphasize this molecular/energy approach. For her, it is important to emphasize that energy is needed to make complex molecules, and that energy is released when complex molecules are broken down, and that chemical energy is stored in bonds. Consequently, she defined the function of photosynthesis at the molecular level: to trap energy in chemical bonds. None of the other teachers in the study described the function of photosynthesis at this level. The teacher's description of the photosynthesis process was also molecular: attaching molecules to one another and trapping energy in chemical bonds. She related cellular respiration to photosynthesis through the use of this molecular/energy approach. She described respiration as the process of breaking down the chemical bonds to liberate energy for cell activity. She also used the same approach to relate photosynthesis to food/nutrition, and emphasized the energy approach in discussing energy wastage in food chains.

The Subject Knowledge and Beliefs category is echoed in the Photosynthesis TPC in a second way as well. Teacher BA clearly stated the theme at the beginning of her teaching: energy is released when complex molecules are broken apart and required when molecules are built. She changed the sequence of topics to start with energy release, or respiration, the first part of her theme. She explained how this released energy is transferred by ATP to other locations in the cell to be used in several cell processes. She compared respiration and fermentation, another energy releasing process. Finally, she asked about the origin of glucose (and the chemical energy in it) that is used in respiration. This led her to discuss photosynthesis as an energy-requiring process. BA also stated that she would usually teach photosynthesis as the second topic in a unit on cell energy, the first unit of which would deal with the chemistry of life. Incidentally, here we notice the integration of the Photosynthesis TPC with another general knowledge category—Curricular Knowledge.

The Subject Matter Knowledge and Beliefs category (in Figure 3) is echoed in the Photosynthesis TPC (in Figure 4) in yet a third way. The knowledge representations (examples, analogies, activities) that she uses also emphasize the molecular/energy

approach to subject matter. In the planning interview, teacher BA explained the function of respiration and the use of cell energy as follows:

> Sometimes the students don't understand what the cells need energy for. … I say, 'I am living in this house, OK? And somebody missed the turn on my street and ran their car through my wall. There's a big hole in my wall, in my house. … What am I gonna have to do?' They say, 'You're gonna have to get bricks, and you're gonna have to get wood, and you're gonna have to build a new wall.' I say, 'What does it take?' They say, 'It takes energy.' I say, 'We've got a cell here, and right here this membrane ruptures. What's the cell gonna do?' 'The cell is gonna have to fix it.' 'What's the cell need to fix it?' 'Oh, it needs proteins and it needs building blocks.' I say, 'What is it gonna have to do to hook one protein molecule to the next, to make them stick as one atom to the next?' 'It needs energy.' I say, 'That's one of the things that you do cellular respiration for.' (Hashweh, 1985, p. 243)

This teacher had developed a repertoire of analogies for use in teaching photosynthesis, most of them reflecting her molecular/energy orientation. She was aware of particular student difficulties (another important aspect of PCK) and had developed analogies to help students overcome these difficulties:

> If the students understand that ATP is an energy-carrying molecule; its job is to take the energy from the mitochondrion and take it to whatever part of the cell that needs that energy, then it just breaks apart and goes back and does it all over again. And they say, 'Don't you mean it's used up there?' And I say, 'No, it just drops off the energy.'
>
> And I do the shopping cart analogy, or a paper bag analogy. I say, 'How many of you shop at Lucky'. I say, 'OK, do you know they pay you five cents if you bring back the paper bag?' 'Oh, my Lucky is only two cents,' you know. 'In Palo Alto they give you five cents because we like our trees.' So I say, 'I take this paper bag, think about it as ADP. And I take it to the grocery store, and I fill it with food, and I bring it home again. And I take the food out, and what do I do with the food?' 'Well, you eat it.' And I say, 'What for?' 'Ha ha, to get fat.' And then they say, 'For energy.' I say, 'Fine, what am I gonna do with this paper bag?' 'You're gonna take it back to the store and get more.' I say, 'Exactly. And that's what happens with ADP: it goes back to the mitochondrion, which is just like the grocery store for energy, get food, take it to whatever part. You know, what if I'm gonna go on a picnic? I'm not going to take it to my house; I'm going to take it to a different place. But I'm gonna empty the bag out, I'm gonna take the bag back to the grocery store. Just do it over and over.' And sometimes they grasp that. I like that analogy too. (Hashweh. 1985, p. 239)

The general Aims and Purposes category for this teacher includes, as one of her aims for science teaching, the development of students' environmental awareness. She used the photosynthesis topic (and probably other topics that she finds appropriate) to realize this aim, and allocated time to discuss the region's ecology.

The general Knowledge and Beliefs about Learning and Learners category (Figure 3) is also echoed in the Photosynthesis TPC (Figure 4). Biology teacher BA subscribed to what might be called a cognitive view of learning:

> I like to do what's called an overview. And I like to show them how this particular subject that we're dealing with ties into stuff that they already own, how it fits into stuff that they've learned about … I help them fit it into their intellectual framework if possible. (Hashweh, 1985, p. 259)

The teacher thought it was crucial for students to express their ideas in class because she believed in the active role of the learner, and discussed the methods she used in class to allow this to occur. She also thought that students come to science classrooms with alternative conceptions of science phenomena. The corresponding TPC student characteristics category includes knowledge about the specific alternative conceptions that students hold, for example, that they think plants only photosynthesize but do not respire. The teacher's TPC also shows she had developed a strategy that might be termed 'applying science framework to situation' to confront this alternative conception. BA, when planning to teach respiration and photosynthesis, started by providing the larger scientific framework: how building complex molecules requires energy while breaking-up complex ones releases energy, and how energy is needed for vital cellular processes. Within this framework, BA showed that every cell needs to provide energy for these cellular processes or 'it's dead meat'. Respiration, she explained, was the mechanism for providing this energy. In summary, BA's strategy depended on showing that from a scientific point of view it is expected that all living cells, whether plant or animal cells, respire. The influence of conceptions of learning and the learners on the use of strategies that facilitate learning becomes clearer if we compare this teacher to another physics teacher in the same study who subscribed to a conceptual change view of learning and who used strategies that directly confronted students' alternative conceptions.

I have emphasized in this section how the interaction between different knowledge and beliefs categories affects PCK, and how we can find traces of the original general knowledge and beliefs categories in PCK or in a particular TPC. However, there are indications that the original beliefs, in particular, are not only echoed in PCK, but that certain beliefs are more favorable than others to the development of rich PCK. Hashweh (1985), using a qualitative approach, found that teachers holding constructivist beliefs about knowledge and learning are cognizant of their students' prior ideas and alternative conceptions related to a certain topic, while teachers holding empiricist beliefs were not aware of the students' characteristics related to the same topic. In a later study, that employed a more quantitative approach (Hashweh, 1996), a similar conclusion was reached: teachers holding constructivist views have developed richer PCK compared to empiricist teachers. Masalmeh (1998) replicated these findings when studying secondary school chemistry teachers. It seems that, not only does PCK have a beliefs component, but that certain beliefs are more favorable than others to the development of rich PCK.

Pedagogical constructions have components of both generalized event-based and story-based memories

We should not be led to believe that the neat organization of knowledge represented in the figures really represents teachers' TPCs; this representation, extracted from teachers' responses to tasks that examined their planning using thinking-aloud and stimulated recall techniques, or that examined their teaching using the critical-incident technique, enforces an order on teacher knowledge for analytic purposes. It

emphasizes the general event-based memory for TPCs. The concept of event-based memory proposed by Schank (2000) is similar to the familiar concept of semantic memory long used in cognitive psychology. It refers to the continuous updating and organization of our general knowledge base through experience. Teachers seem to develop a schema, or a script, that organizes and stores their memory for any single TPC. Restaurant goers develop restaurant scripts that describe their experience—it allows them to comprehend the series of events, to predict what will happen and to exhibit the proper conduct. Similarly, a teacher who teaches a topic regularly develops a script that describes the typical sequence of events in teaching the topic. Among other things, the teacher comes to know in advance what knowledge, alternative conceptions, and interests the typical student brings to the study of the topic, what difficulties he or she will face, and how best to engage these prior ideas and confront difficulties. He or she knows what knowledge representations to use, and how to use them.

In reality however, teacher knowledge is more undifferentiated, with a narrative or story-based character as well. Schank has proposed that we disconnect the events when we update our general knowledge categories (event-based memory):

> … actual experiences are constantly being broken up into their component pieces and are being added to general event memory bit by bit in different places [and] no coherent whole remains. (Schank, 2000, p. 122)

In contrast, story-based memory allows us to remember events in sequence.

> Story-based knowledge expresses our points of view and philosophy of life and, as it comes from experience, is closer in spirit to what psychologists have meant when they have spoken of episodic memory. (Schank, 2000, p. 125)

Analogies, examples, films, the purposes for using them, and the way they are used are all intertwined in a narrative, a story that the teacher remembers about teaching a certain topic. For example, analogies and examples are not separated in the teacher's mind from the way they are used in class. We have seen this previously when the biology teacher talked about the analogies she uses—she described the analogy, the typical exchange with her students when she uses it, and her feelings about it. BA actually mentioned four analogies that she uses to help her students understand the role of ATP and how it functions when teaching photosynthesis (Hashweh, 1985). The description of the analogies, and more generally the knowledge representations, their use, and the typical conversation that takes place in class was common to all teachers in the study, and not unique to this one. The following excerpt is about the use of the first analogy.

> I do things very physically when I'm talking to them … and when I'm talking about this I say, 'OK, here's a carbon and here's a carbon. And how am I gonna get them together?' [She brings her fists together pretending she has to exert an effort to overcome the repulsion they have for each other.] They say, 'You're gonna push them.' I say, 'OK, now what do I have here? I have a bond. OK, now could you come up here, please, could you break these two hands apart?' And the kids will go like this, and my hands will fly apart. And I say, 'What just got released?' And they say, 'Energy'. (p. 292)

Teacher pedagogical constructions are cases of repeated experiences of teaching a familiar topic. In my opinion (see Hashweh, 2004) they represent an intertwining of knowledge categories that are usually conceived as separate and contrasting—dualisms that emphasize sharp conceptual distinctions with clear boundaries: theoretical versus practical knowledge, declarative versus procedural knowledge, research versus narration, emotion versus cognition. Those of use who have listened to teachers narrate their stories of professional practice have become skeptical about these dualisms. If anything, teacher professional constructions reveal the importance of border crossing, of intertwining the practical and the theoretical, emotion and cognition, research or systematic investigations and narration. Recently, Gudmundsdottir's use of the term narrative research (2001) challenges the traditional distinction between research and narrative. Schank (2000) finds limitations with the traditional episodic/semantic distinction in cognitive psychology, and proposed the distinction I used above between story-based memory and generalized event-based memory. Schank, however, makes it clear that even this distinction is not always true. In the case of a teacher pedagogical construction the teacher knows what preconceptions exist and what anomalies can be used to confront them (generalized scripts) but he might also remember what happened the last time he used them with a specific student (story-based memory).

Pedagogical constructions are topic-specific cases, yet labeled in multiple interesting ways

Assertions 6 and 7, taken together, portray a picture of each TPC as, firstly, being mainly connected in memory to a certain topic that the teacher regularly uses. This explains why some researchers considered PCK as a subcategory of subject matter knowledge. Each topic acts as an index or label that helps the teacher recall the associated TPC when required: photosynthesis is a label that triggers the photosynthesis TPC in memory.

However, the topic is just the surface feature of the TPC. There are other more interesting features of the TPC that allow it to be used in other situations. These are the labels exemplified by the relations between the TPC and other general categories of teacher knowledge and beliefs. A teacher might use the students' characteristics category, or, specifically, the alternative misconceptions subcategory, to remind him of specific misconceptions about photosynthesis—knowledge that is stored in the Photosynthesis TPC. The label in this case was student alternative conceptions, and not photosynthesis in the teacher's subject matter category. However, we should not be led to believe that there is a close one-to-one correspondence between each subcategory of a TPC and the corresponding general category of teacher knowledge for all teachers. There are probably many different interesting ways that teachers relate a TPC to other entities in their memory. This depends on how teachers label or index (Schank, 2000) their TPCs.

We can view the relations between a TPC and other knowledge and beliefs categories as representing relations in an event-based general memory and as representing relations in semantic memory, where in the second case they represent a logical

relation, for instance between the general pedagogical category (using anomalous examples to confront alternative conceptions) and a specific TPC (using a specific demonstration to show that only the tip of a plant's stem grows and not all the stem, for example).

On the other hand, when teachers store their TPC in a story-based manner then the key to using it in new novel situations, when there are no available scripts to use, is in labeling it in a clever manner. In this case, the teacher thinks analogically, from the concrete past experience to the new novel concrete situation. He or she has to remember a past precedent, to see it as a precedent. As Schank (2000) suggests, to remember something someone would have to have cleverly labeled it in the first place. One way to do this is to reflect over the original experience, to mull over it, and to see it as a case of something, that is, to label it. Telling the story to others also is crucially important because it preserves it in memory as a single unit. Otherwise, the components of this event or story would be used to update our knowledge in other categories, and the unity of the event would be lost (see Shank, 2000, for a detailed treatment of this point). Consequently, we see that storing the TPC in a story-based manner is important since it allows us to use it in future novel situations. However, to store it as a story one has to label it and to inform others about it.

Whether a TPC is stored as general event-based, (scripts or schemas), or as stories, the main determinant for its future use is its integration into the memory structure of the teacher, the organization of this memory, and the labeling of these TPC. Teachers use a TPC when it is well-connected to other memory entities, when it is labeled in multiple interesting ways.

Conclusion

In this article I have called for viewing PCK as neither a subcategory of subject matter (subject matter knowledge for teaching) nor as a generic all-encompassing form of knowledge. I presented a view of PCK as a collection of teacher professional constructions, as a form of knowledge that preserves the planning and wisdom of practice that the teacher acquires when repeatedly teaching a certain topic. Viewing PCK as a collection of TPCs, more precisely defining it, clarifying its relations to other knowledge and beliefs entities, and speculating about its development should hopefully facilitate future investigations of PCK.

A certain TPC, like an architectural construction, can now be examined in multiple ways to evaluate its scientific and theoretical bases, its technical dimensions, the values embedded in it, its utility and functionality, and its aesthetic qualities. It can come to exemplify a certain philosophy and approach to teaching, and become associated with the name of its designer. Detailed descriptions of teaching of certain ideas or topics by some teacher researchers come close to that (Lampert, 1990; Ball, 1993). However, as in schools of architecture, one does not teach these TPCs to future teachers in a stand-alone mode; these designs are used as precedents, but closely taught in conjunction with the theory with which they are associated. They represent the end product of an inventive process that was based on other important intellectual

entities, and future teachers should be exposed to the whole conceptual ecology that forms the context for a TPC, not just the TPC alone. Gudmundsdottir's insistence on the value-laden and narrative nature of PCK served to direct us to the need to check our reductionist tendencies, to look at the whole, and to reconfigure pedagogical content knowledge: to view it as a repertoire of teacher pedagogical constructions.

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