

Pedagogical Content Knowledge as a tool to understand and develop teachers’ competences

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Abstract

This paper addresses the research problem of relating the knowledge base for science teaching with teachers’ professional competences. An investigation about how professional competences are perceived by 16 expert science teachers and 132 prospective teachers of two Italian Universities has been carried out. Different kinds of data have been analyzed according to qualitative research methods. Data analysis allowed us to categorize the competences recognized by expert teachers in the most acknowledged three areas of Shulman’s classification (Pedagogical Knowledge, Subject Matter Knowledge, and Pedagogical Content Knowledge). Results are discussed in the perspective of teacher preparation interventions aimed at addressing the problem of competences’ development as a fruitful framework for designing teacher education courses.

Sommario

Questo articolo affronta la problematica del mettere in relazione le conoscenze di base necessarie per l’insegnamento delle discipline scientifiche con le effettive competenze professionali degli insegnanti. Viene presentato uno studio sulla percezione delle competenze professionali da parte di 16 docenti esperti di Scienze e di 132 studenti delle Scuole di Specializzazione all’Insegnamento (S.S.I.S.). Seguendo i metodi dell’analisi qualitativa, sono stati analizzati diversi tipi di dati e la loro analisi ha permesso una categorizzazione delle competenze individuate dai docenti esperti nelle tre aree della classificazione di Shulman (Conoscenza Pedagogica, Conoscenza del Contenuto Disciplinare e Conoscenza Pedagogica del Contenuto). I risultati dell’analisi vengono qui discussi relativamente alla costruzione di percorsi di formazione orientati alle problematiche relative allo sviluppo delle competenze, nell’ottica della progettazione efficace di corsi di formazione per gli insegnanti.

1. Introduction

Research on the characteristics of teachers’ knowledge begun with the Shulman’s claim that teaching is a profession (Shulman, 1987). This political goal of professionalizing teaching is based on the belief that it is possible to identify a knowledge base for teaching founding teachers’ behaviours (Hoyle & John, 1995).

During the past two decades, Pedagogical Content Knowledge (PCK) has been a debated framework for teacher education research due to its capability of framing and re-directing the relation between research and practice.

The framing aspect involves the ways of dealing with PCK; literature mainly reports various methods that try to model PCK by means of conceptual structures through which to analyse teachers’ knowledge base of teaching, as well as to capture PCK characteristics by means of existing methods and techniques to analyse actions/ideas of an expert teacher.

The re-directing aspect mainly concerns the research development within the framework of teacher education. Implications in this field are seen as natural outcomes of studies focused on PCK in order to design teacher preparation courses in which the domains of teaching knowledge are simultaneously developed.

Nevertheless, being PCK linked to very specific instructional variables, such as pupils' characteristics, school's context, teacher's subject matter and pedagogical knowledge the task of defining PCK proved to be a challenging one (Hashweh, 2005; Loughran et al., 2006). Moreover, research has shown that another difficult task has been that of portraying PCK's development and assessment (Magnusson et al. 1999). Consequently, use of the PCK as a conceptual tool (Park & Oliver, 2008) to effectively affect educational practice faces many difficulties.

In this paper we propose to tackle these issues: - firstly by framing a model of PCK in terms of the “competence” concept as defined by experienced teachers; - secondly, by designing an approach aimed at helping prospective teacher to develop appropriate PCK for their future profession and re-directing teacher education programs.

In the next section, we outline the theoretical background of our research. Next, the research design, data analysis and results of our study are presented and discussed. Finally, implications for the design of science teacher education interventions are drawn.

2. Theoretical background

2.1. The problem of knowledge of teaching

Many studies about the knowledge base of teaching started from the assumption that such kind of knowledge “was supposedly shared by teachers and formed the basis for their behaviour” (Verloop et al., 2001, p.441) and that it could be represented in some form (proposition, argument, painting, or artefact) (Hoyle & John, 1995). These studies can be divided into two broad categories, those focused on the teacher “practical knowledge” and those focused on the pedagogical content knowledge as specific forms of teacher knowledge.

Research studies addressing teacher “practical knowledge” (or simply teacher knowledge) assume the existence of relationships between one teacher's actions and his/her whole set of cognitive resources available in a certain situation. Some authors used labels, such as “personal knowledge”, “professional craft knowledge”, “action oriented knowledge” or “content and context related knowledge” (Brown & McIntyre, 1993; Van Driel, et al., 1998). However, although this knowledge appears to be primarily an individual knowledge and/or a form of tacit knowledge, some aspects, shared by large groups of teachers, have been identified by the research (Van Driel, et al., 2001; Loughran, 2002).

The theoretical construct of PCK (Shulman, 1986, 1987) is intended as the transformation, performed by an “expert” teacher, of the “classic” Subject Matter Knowledge (SMK) (quantity, quality and organization of information, conceptualizations and underlying constructs in the subject area he/she is teaching) into a knowledge appropriate for teaching. As cornerstones of such knowledge base for teaching, two other general areas of knowledge have been also defined: Pedagogical Knowledge (PK, generally defined as knowledge concerning learning and learners, knowledge of general principles of instructions, knowledge related to classroom management, and knowledge about the aims and purposes of education) and Context Knowledge (CK, including knowledge of school setting, for example culture and knowledge of individuals). Due to the complex nature of the teaching/learning process, all these three areas of knowledge SMK, PK and CK are inextricably connected to PCK, once applied into concrete teaching.

2.2. Framing Pedagogical Content Knowledge

Many researches modelled PCK as a distinct knowledge domain which encompasses other knowledge domains, mainly SMK and PK (Magnusson, et al., 1999; De Jong, 2003). Other researches tried to analyse to what extent subject matter knowledge is a separate domain (Adams & Krockover, 1997; Van Driel, et al., 1998) or it is included in PCK (Fernandez-Balboa & Stiehl, 1995; Turner-Bisset, 2001). A different research line analyses the differences between experts and novices teachers (Clermont, et al., 1993; Clermont, et al., 1994; Lederman, Gess-Newsome & Latz, 1994; Mellado, 1998) or exploits tools to systematically trace PCK of expert teachers (Loughran et al., 2001; Loughran, et al., 2004).

More recent study (Sperandeo Mineo, et al., 2006; Park & Oliver, 2008) supplies a refinement of the construct of PCK where different components are pointed out and their coherence and integration is outlined.

This collection of research studies places emphasis on the importance of teachers' disciplinary competence, as well as on their personal experience of the teaching process. Moreover, they show that it is also es-

essential for teachers to be able to devise and deploy the pedagogical resources appropriate to teaching the topic at hand, which draw upon general pedagogical theories and take into account the constraints imposed by the teaching context (as for example, the specifics associated with the intended learning outcomes, the known learning difficulties,.....). As a consequence, a model, even if coarse and partial, of knowledge for teaching that can professionally characterise the science teacher has to be deployed in terms of competences rather than in terms of simple contents/topics. In this perspective, modelling PCK points to the relevant competences involved in the teaching a topic, where the term . competence is intended as the capacity to mobilize different cognitive resources, to meet a certain type of situation (Evers, et al., 1998; Perrenaud, 2000).

Le Boterf (1994) defines different kinds of resources for teaching, in the sense of “knowing how to act”, “knowing how to do”, However, competences are different from resources in the fact that the former mobilize, integrate and orchestrate such resources. This mobilization is only pertinent in a situation that could be tackled according to similar previous experiences. The development of competences, then, involves the meta-reflection abilities about the nature of knowledge involved.

In the field of teacher education, Shön (1983) introduces the term “meta-learning development” as a reflective practice that should be adopted in all aspects of teaching-practice supervision. He defines the learning activity as the process of making sense of complexity or reflection-in-action, and introduces a second reflective domain relevant to the objective of learning to teach, the reflection-on-action, i.e. the thought used to review the complex teaching/learning interaction by sense-making of it. This aspect is relevant for the conceptualization of competences in order to make them recognizable and reproducible (Simons, 1996) and meta-reflection activities will be the methodological base of our empirical research.

2.3 Re-directing teacher education on the base of findings about PCK

Implications in the field of teacher education are seen as natural outcomes of studies focused on PCK. Some studies have made evident that specially designed workshops/programs can affect prospective teachers’ PCK. These can be categorized in two main broad categories, those focused on modifying and/or improving prospective teachers’ knowledge about subject matter (Aiello & Sperandeo Mineo, 2000; Lederman, et al., 1994; Van Driel, et al., 1998; Van Driel, et al., 2002;), and those focused on more general aspects of PCK (Geddis, 1993; Clermont, et al., 1993; Clermont, et al., 1994; Adams & Krockover, 1997; De Jong, 2003; Johnston & Ahtee, 2006). Many of these studies explicitly refer to a specific conceptualization of PCK as a distinct knowledge domain. As a consequence, guidelines for designing teacher preparation courses, in which the domains of teaching knowledge are simultaneously developed have been designed.

Recent research papers (Loughran, et al., 2001; van Driel, et al., 2002) address the point of the effects produced by the different teachers’ conceptions of subject matter as well as of learning/teaching models on the dynamics of the Shulman’ transformation process.

A recent research model (van Dijk & Kattmann, 2007) for the development of science teachers’ PCK, the Educational Reconstruction for Teacher Education (ERTE), gives a framework for an integrative approach to the study of PCK aimed at improving teacher education. It is based on the model of Educational Reconstruction (Duit et al., 2005) that provides a framework for designing and evaluating learning environments or teaching–learning sequences. The ERTE model integrates the following research domains (van Dijk & Kattmann, 2007, p. 894): the design of learning environments, the empirical study of students’ pre-conceptions, the analysis of the subject matter, the design of teacher education PCK-Studies (i.e. the field within educational research that focuses on the PCK that teachers possess that are extracted from their individual context). Briefly, the ERTE model tries to design ways in which results of research about experienced teachers’ PCK can supply new educational ideas for prospective teachers that can be taught in workshops and courses. As a consequence research results are reconstructed for teacher education with the intention that these ideas are internalized by the prospective teachers and form an element of the framework that enables them to learn from their experiences in their own individual teaching practice.

3. Research Design

3.1. Research Question

The reported literature on PCK allow us to identify two broad research problems:

- When framing PCK, both the modelling and capturing approaches do not overcome the difficulty that PCK *is not* a codified knowledge field and hence it is difficult to document it in any “reproducible” way, not directly dependent on the particular context of the specific research.
- Although most recent teacher education programs aim at helping prospective teacher to develop appropriate PCK for their future profession, the transformation process of SMK, PK and CK into PCK is not always effective.

The present study aims at tackling the first problem from the viewpoint of the competences characterizing the professional role of the science teacher, and the second one by proposing an approach to teacher education that uses finding about competences as a tool to develop PCK (see last section).

As a starting point, we assume that competences are related to the knowledge base involved in the teaching process and to observable behaviours. Therefore, we make the further hypothesis that it is possible to envisage from the reflections of an Expert Science Teacher (EST) about his/her own behaviours, beliefs, attitudes and practices, what are the relevant elements of his/her professional profile’s that can be recognized as shared aspects of PCK.

On the basis of such assumptions, our research will mainly focus on the following research question:

- RQ: How can PCK be described in terms of the competences, perceived by ESTs as the most relevant ones for their profession?

Since our research aims at the operative outcome of developing effective approaches/tools in order to improve pre-service teacher education programs, we also focus on possible implication for prospective teachers’ (PTs) education.

3.2. Sample

The investigation involved a group of science teachers (G1) including 16 ESTs that participated, on a voluntary base, to a Focus Group (see next section). 11 of them were engaged as supervisors of the apprenticeship activities by the Graduate School of Teacher Preparation of two Italian Universities, which will be called from now on Un1 and Un2, and 5 of them were PTS’ mentors of the Graduate Program. Their expertise has been evaluated through a contest examination in which the candidate’s publications and academic records were considered. Their participation in seminars, workshops and/or in projects involving innovations in science education was also evaluated.

A sub-group (G2), including 4 physics teachers of the 16 ESTs, were later submitted to in-depth interviews about their teaching practice (see next section). This sub-sample has been selected taking into account our objective of improving pre-service preparation of physics teachers.

4. Methods

4.1 The focus group

The whole sample of ESTs participated to a four hours group-work, based on individual and group reflection activities, and aimed at focusing on the competences related to their role of science teachers. ESTs were requested to analyze their successful and unsuccessful teaching experiences with the aim of recognizing which competences they acted, or not acted, in such occasions. A researcher participated to all the phases of the activities by taking notes in a logbook of questions and details of discussions.

At the beginning of the focus group (phase I, about ½ hour) a researcher in cognitive science described some research results about the professional competences of teachers and educators. Consequently, a working definition of competence was negotiated with the ESTs as that set/mixture of behaviours, knowledge, abilities, cognition, the teacher puts in practice in class and in particular when faced with problematic situations, in order to seek for possible solutions.

Later on (phase II, about 2 hours), ESTs were requested to generate a list of competences, that allowed to define a “profile” of a “professional teacher” by focusing on those responsibilities, behaviours, abilities, required on behalf of science teachers, that favour the development of an educational process aimed at effective student learning. ESTs of the same discipline worked in groups of two or three. The group’s discussion was facilitated by the researcher who, now and then, introduced whole group discussion in order to avoid di-

gressions toward very particular details. This phase of the workshop ended with the presentation by each group of a list of negotiated competences.

The third phase (about 1 hour and half) was devoted to compare the groups' lists and to discuss the reasons of the choices they made. The whole group discussion, guided by the researcher, led to a common agreed list of 47 competences by merging the competences considered equivalent and/or focusing on the competences' differences.

The transcripts of the final discussion supplied useful indications about the meaning of statements as well as of the merging process of the different competences proposed by each group of teachers as result of the Phase II work. During the discussion, the ESTs groups' lists of competences were shared in order to find out similarities and differences.

4.2 The interviews

The sub-group of four ESTs (G2 group) were later exposed to a stimulated recall interview (Leinhardt, et al., 1995) in order to point out examples of those teaching/learning situations where, in their opinion, some of the listed competences had been put into practice. We involved in the interviews only four physics teachers out of the sixteen ESTs since we were interested in deepening the relationship between competences and specific aspects of the knowledge base of teaching related to a disciplinary content (in our case in the physics area).

The interviews have been conducted by two researchers of both Un1 and Un2 on the base of a pre-prepared semi-structured protocol reported in Appendix; while one conducted the interview the second researcher was taking notes. At the beginning, the interviewer described the objective of the interview and encouraged the teacher to recall a particular teaching/learning intervention where he/she had to put into practice some of the competences recognized as fundamental for a good physics teacher. In particular, the teacher was required, in relation to a particular teaching episode, to carefully describe the teaching/learning situation and to focus on what he/she perceived as main ideas or concepts as well as on what didactical choices (tools, sequences, ...) had been useful to help their students to understand these ideas. Finally, the teacher was required to make explicit the reasons of his/her choices in order to point out the rationale of the intervention. In some cases, the interviewer encouraged the EST to give extensive explanation of the chosen learning situation, by asking, e.g.: “Why did you plan this activity?” or “Why did you ask this question?”

A deeper understanding of what ESTs referred to, when describing specific competences (related to a disciplinary content), has been provided by the analysis of the transcripts of the four ESTs' interviews. As for focus group data, we resort to teachers' descriptions (i. e. their words) and not to observations of their behaviour in classrooms, since the main goal of our research was to investigate the ways teachers conceptualize/rationalize the knowledge base underlying their behaviour.

The interviews' transcripts have been analyzed by two researchers in order to make evident the objectives of the reported teaching episodes, the different steps, the teaching strategies and, mainly, the motivations that guided the particular choices.

4.3 Data analysis

Our research adopts a phenomenographic approach (Marton & Booth, 1997) that focuses on how individuals describe, conceptualize, understand, perceive, etc... phenomena and/or aspects of the world around us. In fact, our study relies on the analysis of ESTs' reflections about their practice in order to identify a set of categories of descriptions (logically related and empirically grounded) characterizing the ways in which ESTs conceptualize their teaching experience in terms of the professional competences that highlight qualitatively different aspects of their knowledge base of teaching.

The characterization of the qualitatively different categories of individuals' descriptions of a given phenomenon is the main feature of the approach that is relevant for our research; these categories represent the variation in ways of conceptualizing the phenomenon at the collective level, i. e., “a stripped description in which the structure and essential meaning of the differing ways of experiencing the phenomenon are retained, while the specific flavours, the scents, and the colours of the worlds of the individuals have been abandoned” (Marton & Booth; 1997, p. 114). The second feature of this approach which is relevant for our

research is the assumption that individuals may express qualitatively different ways of conceptualizing the very same phenomenon depending on the specific context (Bowden et al., 1992).

Unlike previous phenomenographic studies involving teachers’ conceptions about teaching and approaches to teaching (Prosser, et al., 1994) based on interviews and direct observation of teachers’ behaviours in their classrooms, our study refers to teachers’ categories of conceptualizations and representations of the teaching/learning process as reported by their statements and propositions.

Differences and similarities amongst the various competences of the list produced by our G1 group have been used to generate, as final outcome space of the study, phenomenographic sub-categories of competences. The analysis has been performed by focusing on words, semantic contents, perspectives,... defining and giving meaning to each sub-category. Due to the focus of our research, differences amongst the competences have been identified taking into account also the literature about the knowledge base of teaching (see previous section). We called this outcome space competence clusters since more than one competence falls into each category.

The overall analysis has been performed by two researchers of Un1 and Un2 who worked independently. Although the boundaries amongst the clusters were somewhat not rigid ones, the inter-rater agreement between the two coders was high (more than 70% of the global list of competences have been assigned by the two researchers to the same clusters) and the few cases of disagreements have been negotiated and resolved in order to share a consensus. Negotiation was necessary in those cases where competences were considered on the boundaries. Each competence was therefore coded in only one of the clusters.

5. Results

5.1 The competence clusters

Through all the sessions of the group work, ESTs pointed out that the profile of the “good science teacher” has to include some general features, relevant for teaching science and other disciplines, that are subject or disciplinary content independent; these features refer essentially to teacher’s global and verbal knowledge and to his/her beliefs and attitudes and are transversal to all teaching/learning processes. Since we were mainly focused on the competences useful for science teaching we did not analyze them.

Moreover, the whole group of ESTs recognised the relevance of a deep knowledge of the discipline (concepts, structures, models, theories and its historical development) as well as of pedagogy (knowledge of learning theories, pedagogical methods and teaching strategies in order to match pupil demands). Both are considered indispensable for a constructivist approach to the teaching/learning environment.

The focus group then addressed the relevant competences in the area of knowledge appropriate for teaching: the PCK.

Table 1 reports the list of “Identified competences” pointed out by G1 group and their classification into competence clusters as derived from the categorization process described in the above section. The “Identified competences” report ESTs’ words except for few case where a rephrasing has been necessary simply to clarify the meaning. In the “Focus on” column, some keywords which characterize distinctively the single cluster with respect to the others are reported.

Table 1. Clusters of competences identified as belonging to the PCK area

Focus on	Identified competences	Cluster
Contents and teaching methods	<ul style="list-style-type: none"> ▪ <i>Transform content knowledge in a appropriate knowledge for teaching.</i> 	a
Contents and learning processes	<ul style="list-style-type: none"> ▪ <i>Activate methods and strategies suitable to help a learner to build his/her own knowledge net.</i> ▪ <i>Correlate the observation of phenomena (i.e. biology, physics, chemistry) to their representations and models agreed upon in the disciplinary knowledge.</i> ▪ <i>Implement constructivist practice for learning.</i> 	Knowledge of the teaching/learning processes related to specific contents

	<ul style="list-style-type: none"> ▪ <i>Reconstruct the subject knowledge in ways/formats appropriate for teaching.</i> 	
Student centered methods related to content (Building knowledge, representations, ...)	<ul style="list-style-type: none"> ▪ <i>Use various models and representations in order to fit students' reasoning.</i> ▪ <i>Guide students in building and organizing their knowledge.</i> ▪ <i>Stimulate students in using different representations (verbal, iconic, mathematical,...) of the same phenomenon.</i> 	b Knowledge of representations of content suitable for teaching
Methods/tools for effective learning activities (Everyday –life, Experimental activity Conceptual maps Laboratory tools Computer,...)	<ul style="list-style-type: none"> ▪ <i>Relate everyday-life phenomena with scientific models.</i> ▪ <i>Favor modeling activities starting from experimental data.</i> ▪ <i>Integrate lab-work with theory.</i> ▪ <i>Use conceptual maps.</i> ▪ <i>Use Information Technologies as cognitive tools.</i> ▪ <i>Use computers as laboratory tools.</i> ▪ <i>Use computers for different representations (verbal, iconic, mathematical,...) of the same data.</i> 	c Knowledge of pedagogical methods and tools aimed at scaffolding learning a given content
Students' ideas	<ul style="list-style-type: none"> ▪ <i>Search for common sense knowledge models used by students.</i> ▪ <i>Identify students' common reasoning strategies.</i> ▪ <i>Search for students' naïve ideas.</i> 	d Knowledge of relevant characteristics of students' common-sense knowledge
Learning obstacles “Difficult” themes	<ul style="list-style-type: none"> ▪ <i>Understand students' difficulties with respect to the objectives targeted by learning materials.</i> ▪ <i>Make appropriate revision in the sequence of learning activities.</i> ▪ <i>Address students' conceptual nodes.</i> 	e Knowledge of students' meaningful understanding of science

A brief description of the meaning of each cluster that takes into account the transcripts of the workshop final discussion is hereafter reported.

- a) Knowledge of learning processes related to specific contents: It refers to the awareness of how pupils elaborate a content during their own learning process; therefore it includes the ability to adapt content knowledge in an appropriate form for teaching as well as to connect observation of phenomena to their representations and models in the framework of the disciplinary body of knowledge.
- b) Knowledge of representations of content suitable for teaching: It includes the knowledge of the most appropriate methods, related to a given content, to take care of different students' cognitive styles, e.g., the capability to use different representations (verbal, iconic, mathematical,...) of the same phenomenon.
- c) Knowledge of pedagogical methods and tools aimed at scaffolding learning of a given content: Unlike cluster b), competences in this cluster point to the importance of a content-centred approach, exploiting methodologies such as, e.g., “to use computers for laboratory work and modelling activities”; “to relate everyday phenomena with scientific models”; “to use the predict-observe-explain learning cycle”, in order to plan and implement successful learning activities.
- d) Knowledge of students' common-sense knowledge: Distinctly to the other clusters in PCK domain, here competences focus exclusively on the awareness of pupils' prior knowledge, naïve ideas, reasoning strategies and schemas, in order to help them to access content matter with appropriate procedures.
- e) Knowledge of students' meaningful understanding of science: It is only this category in which competences focus on the awareness about disciplinary learning knots as epistemological obstacles. The

competences in this cluster have some relationships with the ones in cluster 3b since a teacher needs to know which representations (verbal, iconic, mathematical,...) may reinforce not correct students' interpretations and which ones lead students' to get a correct picture of the addressed content.

5.2 The critical episodes

Since the possibility of rationalizing teachers' knowledge is crucial to design the transferability process in teacher education programs, we have chosen to present the interview transcripts as reports of teaching practice in a semi-tabular form. We call this kind of report critical episode.

The critical episodes are similar to other ways of portraying or describe classroom situations, sometime called “vignettes” (Veal, 2002). They are used in educational research for many purposes; in our case, according to the working definition of competence negotiated during the focus group, we have exploited such kind of vignettes as tools to analyze and highlight more deeply what specific competences teachers act in their classrooms when faced with problematic situations. Furthermore, according to other researchers (Leinhardt, et al., 1995), we used this form of report in order to characterize, through ESTs' description of a real situation, the knowledge base that scaffolds teachers' classroom practices in terms of competences.

Analysis of the transcripts of physics teachers' interviews, presented in the form of critical episodes allows to synthetically envisage how expert teachers rationalized the knowledge base of their behaviours and how they acted some competences that may be basically related to the PCK competences clusters. Tables 2 and 3 report the general features of two of the four critical episodes analysed describing in detail how the teacher faced the teaching situation; i.e., the single steps, the objectives, the teaching strategies and the rationale of the choices (i. e. the motivations that guided the teacher at the particular choices). We also report a short description of the teachers, the class situations, the key topics of the teaching episode and the reasons why each teacher considered this situation as a critical one.

Critical Episode: Teaching about the relationships between macroscopic properties of matter and microscopic models.

Teacher: C. is a 37 years old teacher, graduated in physics, and with about 10 years of experience in teaching physics at high school level (pupils 15-18 years old). According to his colleagues' opinion he is a true expert in the use of new technologies in teaching and has a good pedagogical preparation.

Classroom situation: Teaching gas properties to pupils (17 years old) of the scientific oriented high school (“liceo scientifico”).

Teacher's justification of the subject's choice: *“In my experience one nodal point of physics teaching is to make students aware that scientific knowledge involves not only a description of phenomena but mainly their explanation (on the base of some theory) and that this procedure allows to predict other phenomena. In my opinion this procedure is well depicted in the analysis of gas behavior. Usually my starting point is the discussion of observations (focusing on qualitative relationships among variables); then I organize classroom experiments (in order to find quantitative relationships among variables). Pupils usually believe that the main objective of their study is to find the experimental law; they are astonished when I continue the lesson by asking them “why” or “what, in your opinion, may justify the observed gas behaviour?” For this reason, I wish to report how I manage teaching a part of the study of gases, in particular the relationship between pressure and temperature.”*

Table 2. Critical Episode N° 1:

The teaching of relationships between macroscopic properties of matter and microscopic models.

Steps of the T/L episode	Objectives	Rationale of the Choices	Strategies
I			
The first step involves a discussion about phe-	Reflecting about everyday phenomena and in-	<i>“Usually, my starting point is the analysis of behaviour of objects and/or processes belonging to everyday life in order to stimulate</i>	Small group discussions and analysis of everyday materials (sy-

<p>nomena dealing with the heating of gases by analysing relevant variables and predicting qualitative relationships among them.</p>	<p>vestigating students' ideas about relevant variables (pressure, temperature).</p>	<p><i>pupil interest and engage them in the research for explanations”.</i></p>	<p>ringes, balloons,...). Successively a class discussion sorting with one or more predictions about behaviour of pressure of heated gases.</p>
II			
<p>Performing experiments by controlling variables and obtaining reliable measures.</p>	<p>Establishing order relationships between temperature, pressure and volume.</p>	<p><i>”Before the starting of the laboratory session, I stimulate my pupils to discuss about the planning of the experiment. This is a very important point, since usually pupils are not aware that it is important to control some variables” .</i></p>	<p>Students work in small groups of two or three to perform experiments.</p>
<p><i>”When I teach this topic to younger pupils (15 years olds) sometimes I do not correct them and allow them to perform a wrong experiment (for example to try to measure the variation of pressure of a gas in a balloon). When they see that, although the variation of temperature, the pressure is constant (but the volume is increased) then they understand that they have performed the wrong experiment”.</i></p>			
III			
<p>Analysis of experimental results.</p>	<p>Establishing a mathematical description of the relationships between pressure and temperature (in this case the pressure increase as a linear function of the temperature increase).</p>	<p><i>”Usually my classroom performs the experiments using sensors and data logger. I find these tools very effective for many reasons. For data analysis it can be used the software supplied with the system that is speedy and gives good information. However, sometime I stimulated pupils more interested to use spreadsheets in order to better understand the errors of fitting procedures”.</i></p>	<p>The whole class compares the group experimental results and discusses their physical meaning.</p>
IV			
<p>Ask pupils to describe what they think is happening to the gas molecules (particles) when the gas temperature increases.</p>	<p>Making pupils aware of the possible different representations of the same phenomenon.</p>	<p><i>” Many students think that molecules increase their volume in order to have a total increase of the gas volume. Others think that gas molecules make more apart (increase of the distances between the particles) more or less as a consequence of the increase of temperature.</i></p>	<p>Small group discussions and successively a class discussion where one or more qualitative models are negotiated.</p>
<p><i>Few have some idea about the relationships between motion of particles and temperature”.</i></p>			
V			
<p>- Recalling of qualitative micro-</p>	<p>Defining qualitative relationships</p>	<p><i>” Usually pupils are acquainted with the idea that the wall exerts a force on the ball, but</i></p>	<p>Analysis of software visualising microscopic</p>

<p>scopic models of gas pressure (why does a gas produce a pressure on the walls?).</p> <p>- Introduction of mechanical analogies involving a ball bouncing on a wall, stimulating pupils to analyse forces acting on the ball and on the wall.</p> <p>- A negotiated microscopic definition of pressure is then constructed.</p>	<p>between macroscopic physical variables and microscopic characteristics of particles.</p>	<p><i>not with the vice versa. This involves the need to recall the third principle of dynamics or to recall simple situations”.</i></p> <p><i>”By analysing software visualizing hits between small ball velocity we arrive to a qualitative picture of the microscopic pressure”.</i></p> <p><i>”Pupils understand well that little balls moving with a greater velocity exert a greater pressure on the walls. Then we define the root mean square velocity of balls and the measure of pressure on the walls from a microscopic point of view” .</i></p>	<p>properties of particles.</p>
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VI

<p>Experimenting with the simulated model.</p>	<p>Modelling gases behaviour: particles move in all directions with a mean square speed proportional to temperature.</p> <p>Analysing effects of variation of temperature on the mean speed and on frequency of collision with the container walls.</p>	<p><i>I stimulate pupils to perform an experiment with the simulated model: to vary the mean square velocity and to look at the pressure. To take data and analyse them.</i></p> <p><i>Almost the whole class is usually waiting for a linear relationship between root mean square velocity and pressure. To obtain a quadratic relationship stimulate pupils to analyse in a more deepen way the microscopic pressure concept.</i></p> <p><i>My main objective is the understanding of the qualitative model (the velocity has a double influence, in the impulse in the rate of collision). Successively I perform the calculations to obtain the mathematical expression.</i></p>	<p>Using software that allows variations of microscopic parameters to perform experiments and analysis of data.</p> <p>Classroom discussion and my calculations.</p>
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Critical Episode N° 2: Teaching about velocity (by focusing on its sign)

Teacher: M. is a 60 years old teacher, graduated in Mathematics, and with about 30 years of experience in teaching physics at high school level (pupils 14-18 years old). She has been often involved in local physics education research group activities within the framework of the post graduate teacher education program. She is used to work with new technologies as well as with traditional lab-work.

Classroom situation: Teaching kinematics (velocity) to pupils of third year (15-16 years old) of the scientific oriented high school (“liceo scientifico”).

Teacher’s justification of the subject’s choice: *“In my experience one nodal point is the negative velocity; usually pupils think that velocity is like time, it cannot be negative. When they talk about velocity they use the definition $v = \Delta s / \Delta t$, but it not “naturalized”; they are neither deeply acquainted with the concept of increment nor they are familiar with the concept of limit. Moreover, they have problems with mathematical concepts as function or graph; they know what a straight line is but, at the beginning of the third year, they are not used to associate to it a first order*

equation. Moreover, usually physics is learnt only from textbook and often all the concepts taught seem very far from students’ every-day life, even the velocity. When they perform experiments with motion detector they grasp much better all such concepts since they “see them”. For these reasons, I would like to report here how I address such nodal point”

Table 3. Critical Episode N° 2:

The teaching of the concept of velocity and negative velocity.

Steps of the T/L episode	Rationale sequence	Choice rationale	Strategies
<p>I Performing experiments on students’ walks and displaying s(t) graph.</p>	<p>Reflecting about/free exploration of common phenomena and their abstract representation.</p>	<p><i>“I start telling them how the apparatus works...’ your movement is represented on the screen... , you can start moving in front of the sensor... and take a look at the representation on the screen’... I give them the possibility to understand by themselves... I try not to overwhelm them... I let them explore phenomena freely. ”</i></p>	<p>Only one apparatus. Students, one at the time, walk regularly in front of the motion detector.</p>
<p>II Performing experiments suggested by students.</p>	<p>Connecting students’ perception of motion with iconic representations.</p>	<p><i>“After the free exploration, they start to test some of their own ideas. They decide how to move,... what to move,... .questions emerging are, for example: “If I want the graph to have this appearance.... how I have to move?”</i></p>	<p>Groups of students walk in front of the motion detector. Alternatively, one student uses the software.</p>
<p>III Performing experiments with carts and office chairs .</p>	<p>Addressing regularities/trends in the s(t) experimental graphs.</p>	<p><i>“Then we start to experiment with a cart on a track or with a chair on wheels. They try to obtain the graph they have in their minds,... since for example, the s(t) of a uniform motion is represented in textbooks by a straight line they want to obtain that result. The result has to be a nice, smooth curve,... only later they recognise that what they see can be considered as a straight line even though irregularities are present and that what they see can be verbalized as “I moved in a regular way...”</i> <i>“During this phase my role is to observe, give suggestions, seldom intervene.”.</i></p>	<p>Students work autonomously with a cart moving on a smooth horizontal track.</p>
<p>IV Displaying/discussing graphs of the performed V motions.</p>	<p>Correlating velocity to position displacements: moving away means positive velocity (increasing distances), moving toward means negative velocity (decreasing distances).</p>	<p><i>“With these experiments, they can be guided to understand what the incremental ratio is... because they can measure the points’ coordinates, either on the screen or they can look at the tables representation and perform the incremental ratios”... “The fact that $\Delta s/\Delta t$ is associated to velocity is easier even if not all the students grasp immediately the concept... some students observe that for instance the ratio can be negative”.</i></p>	<p>The whole class discusses the obtained experimental results and their physical meaning.</p>
<p>V Repeating experiments on walks and motions suggested by students displaying</p>	<p>Understanding the concept of negative velocity Addressing relationships between</p>	<p><i>“They well understand the idea of the existence of a negative velocity after two or three times”... “before doing such activities the idea of a negative velocity is strange....</i></p>	<p>The students repeat experiments with the cart on the smooth horizontal track moving away</p>

<p>both $s(t)$ and $v(t)$ graphs.</p>	<p>physics and mathematics.</p>	<p><i>as there is no negative time, so there is no negative velocity, because v is always increasing,... it is linked to movement... I cannot go backwards in time!”</i> <i>“These ideas have also positive consequences for math since you can discuss about the graph of a straight line, the incremental ratio that they have in their math curriculum later on in their studies...”</i></p>	<p>and toward the motion detector.</p>
<p>VI Studying from textbook formal definition of velocity .</p>	<p>Formalisation of concept of velocity.</p>	<p><i>“The students work a lot with the experiments and later they study the same concept on the textbook,....sometimes in this passage they have difficulties, they must be guided to understand what a model is;...in such a way concepts become clear...”</i></p>	<p>Textbook study and comparison with experimental results.</p>

6. Discussion

Literature findings have shown that “PCK is both an external and internal construct, as it is constituted by what a teacher knows, what a teacher does, and the reasons for the teacher’s actions” (Baxter and Lederman, 1999, p. 158). Our research mainly focused on conceptualisation of what a teacher knows and on the reasons for his/her actions; it did not directly analyse teaching actions, although, by stimulating meta-reflection, it tried to make evident the reasons of teacher’ strategic choices.

The phenomenographic analysis of the competence list agreed by ESTs’ supports Shulman’s assumption that an effective transformation of different kinds of knowledge into a knowledge appropriate for teaching is an “expert’s” performance. In fact, although not aware of the PCK theoretical construct, the ESTs sample referred directly to competences which generate new knowledge and produce activities/behaviours effective for the learning process.

The analysis of the focus group data suggests framing aspects; i.e. they shape a model of PCK whose relevant characteristics are codified by means of teaching professional competences. Moreover, the reported critical episodes, which feature competences at play when tackling crucial every-day class situations, help us to capture relevant aspects of PCK in action. In fact, the reported episode can shed light onto the operative knowledge transformation processes which have to be activated when ESTs face their classroom situations. For instance, the meaning of some competences reported in the list (as for example : “Favour modelling activities starting from experimental data”, “Use Information Technologies as cognitive tools”, “Search for students’ naïve ideas”, “Address students’ conceptual nodes”) is made clear, in the critical episodes, through the described specific activities (as reported in Tables 2 and 3).

The reported critical episodes show how a EST did not recover to externally proposed “recipes”, rather he activated, in a coherent and structured way, teaching resources in which he made use of some nodal points of the net of knowledge base of teaching.

In synthesis, ESTs through reflection about their teaching experience can generate a set of statements describing some competences, perceived as the most relevant ones for their profession. Such competences integrate relevant aspects of different knowledge domains (subject matter, pedagogy, context) of the knowledge base of teaching by supplying a useful framing to redirect teacher education.

In the next section, implications of our research results for re-directing methods and contents of teacher education programs are discussed and compared with some suggestions and results reported in the literature.

7. Implications for teacher education

The performed analysis about competences portrayed by ESTs allows us to envisage what areas of teaching knowledge domains have to be addressed in teacher preparation courses, in order to foster the acquisition of effective competences in the area of PCK.

Many researches refer that the development of pre-service teachers’ PCK is a complex problem with not easy solutions. Subject matter education and reflection on one’s own teaching experience are considered ma-

major sources of PCK development by many researchers (Van Driel, et al., 2002; Bryan & Abell, 1999). Other researchers suggest a model of teacher professional growth (Clarke & Hollingsworth, 2002) mainly based on learning from teaching and on meta-reflection.

Our assumption is that learning from teaching can be intended as learning by reflecting on own teaching experiences as well as learning by reflecting on valuable examples of good practice (supplied e.g., through videos and/or transcripts) and by comparing and contrasting them with own ideas about teaching. In particular, by eliciting PTs' ideas on effective science teacher competences and exposing them, since the beginning of their professional career, to selected examples that make effective the teaching action, may support the development of a sound knowledge of teaching (Sassi et al., 2005).

What emerges from previous research (Stofflet, 1994) is that teacher education programs which expose PTs (both at elementary and secondary level) to innovative teaching strategies (such as cognitive conflict, accommodation of concepts, predict-observe-explain cycle, etc.) to support conceptual change can be effective in changing their initial attitudes towards the same strategies. Moreover, the ERTE model (van Dijk and Kattmann, 2007) reports how results of research about PCK can then be used to improve teacher education.

In this context, the analysis of examples of good practice can supply the appropriate learning environment making PTs aware of the difficulties connected with the teaching/learning of a given topic and of the different competences necessary to make them explicit as well as to solve them. Evidences drawn from the investigation of some examples of good practice (critical episodes) (in which the competences of the identified clusters come at play) can be used to challenge PTs' ideas about appropriate teaching strategies that can support meaningful learning and stimulate them in the direction of the acquisition of suitable teaching competences. PTs can be stimulated to reflect on actual effective teaching practice and compare competences actually at play with their own naïve ideas or reference epistemologies of what should be the role and the goals of a science teacher in his/her classroom activities. The shown examples should aim at making intelligible the competences' clusters conceptually unfolded, by focusing on evident words, actions, tools.

This approach can supply many pedagogical advantages for the construction of an appropriate PCK. In fact, the competences that can be envisaged as crucial in each critical episode are anchored to a disciplinary content and a situated context. In this way, techniques, methods, and cognitive tools used by ESTs when facing the problem of transforming the disciplinary content into one suitable for teaching are made explicit and the difference/similarity with respect to PT's existing conceptions can be facilitated. Moreover, critical episodes, similar to the ones described, can be analyzed and/or even implemented by prospective teachers in small groups learning activities or during their apprenticeship. In fact, they cover only well defined disciplinary knots and/or competences' clusters.

8. Conclusions

Our research aimed at addressing the two problems of framing and re-directing the PCK from the viewpoint of science teachers' professional competences.

The survey about ESTs' perception of what should be the competences of an effective science teacher allowed us to provide support for framing such competences in relation to the knowledge base for the teaching domain of PCK where competence clusters have been identified.

In order to deepen the meaning of such competence clusters, a major focus has been put on a narrative picture, called "critical episode of teaching" that shows how such can be exploited.

Our hypothesis is that, as research based approaches can favour pupils' grasping of otherwise difficult to address disciplinary concepts, real portraits of teacher professional engagement in classroom activities can favour PTs' shaping of their own knowledge base of teaching.

Finally, since studies on the impact on teaching practice of EST's knowledge base of teaching are nowadays available (Sassi, et al., 2005; Park & Oliver, 2007), future research should focus on it, taking into account that the process of knowledge transformation from subject-matter knowledge to pedagogical content knowledge is not an unidirectional one (Kinach, 2002; Sperandeo Mineo et al., 2006); a richer understanding of the contents and concepts is also gained (Van Driel et al. 1998).

Our framing of PCK and its representation in action through the critical episodes stress the importance of coherence and integration among the different clusters of PCK for effective teaching. Teacher educators,

whether working with pre-service or in-service teachers, need to be aware of the relevance of reflection as a major vehicle to improve teachers' skills to integrate the components of PCK.

Appendix

G2 interview protocol

Q1: Let us focus on a topic which you consider, from your experience, particularly significant and/or difficult to be taught and for which you have to exploit some of your professional competences as physics teacher to address it.

Q2: Briefly explain why you think this topic is difficult for the students.

Q3: Briefly explain the whole typical learning situation (average age level of the students, tools, activities set up) in which you address this topic.

Q4: Recall the most significant steps of the performed activities and briefly justify the didactical choices underlying them.

Q5: Briefly explain which are the main ideas and/or concepts on which you usually focus during the activities.

Q6: Briefly explain how the students work during such activities.

Q7: Briefly explain which are, in your opinion, the main didactical choices you made (set up, tools, strategies, ...) which significantly helped the students in understanding the addressed topic.

References

- Adams, P.E., & Krockover, G.H. (1997). Beginning Science Teacher cognition and its origins in the pre-service secondary science teacher program. *Journal of Research in Science Teaching*, 34, 633-653.
- Aiello, M. L., & Sperandeo-Mineo, R. M. (2000). Educational reconstruction of physics content to be taught and pre-service teacher training: a case study. *International Journal of Science Education*, 22, 1085-1097.
- Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp.147-161). Dordrecht, The Netherlands: Kluwer.
- Bowden, J., Dall'Alba, G., Martin, E., Masters, G., Laurillard, D., Marton, F., Ramsden, P., & Stephanou, A. (1992). Displacement, velocity and frames of reference: Phenomenographic studies of students' understanding and some implications for teaching and assessment. *American Journal of Physics*, 60, 262-268.
- Brown, S., & McIntyre, D. (1993). *Making sense of teaching*. Buckingham: Open University Press.
- Bryan, L.A., & Abell, S. K. (1999). Development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching*, 36, 121-139.
- Clarke, D.J., & Hollingsworth, H. (2002). Elaborating a Model of Teacher Professional Growth. *Teacher and Teacher Education*, 18, 947-967.
- Clermont, C.P., Borko, H., & Krajcik, J.S. (1994). Comparative Study of the Pedagogical Content Knowledge of experienced and novice chemical demonstrator. *Journal of Research in Science Teaching*, 31, 419-441.
- Clermont, C.P., Krajcik, J.S., & Borko, H. (1993). The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators. *Journal of Research in Science Teaching*, 30, 21-43.
- De Jong, O. (2003). Exploring Science Teachers' Pedagogical Content Knowledge. In D. Psillos et al. (Eds), *Science Education Research in the knowledge-based Society* (pp. 373-381). Dordrecht, The Netherlands: Kluwer Academic Publishers.

- Duit, R., Gropengießer, H., & Kattmann, U. (2005). Towards science education research that is relevant for improving practice: The model of educational reconstruction. In H.E. Fischer, Ed., *Developing standards in research on science education* (pp. 1-9). London: Taylor & Francis.
- Evers, F. T., Rush, J. C., & Berdrow, I. (1998). *The Bases of Competence: Skills for Lifelong Learning and Employability*, San Francisco: Jossey-Bass Inc.
- Fernandez-Balboa, J.M., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching & Teacher Education*, 11, 293-306.
- Geddis, A.N. (1993). Transforming subject-matter knowledge: the role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education*, 15, 673-683.
- Hashweh, M. Z. (2005). Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge. *Teachers and Teaching: Theory and Practice*, 11(3), 273–292.
- Hoyle, E., & John, P. D. (1995). *Professional knowledge and professional practice*. London/New York: Cassell.
- Johnston, J., & Ahtee, M. (2006). Comparing Primary Student Teachers' Attitudes, Subject Knowledge and Pedagogical Content Knowledge Needs in a Physics Activity. *Teaching & Teacher Education*, 22, 503-512.
- Kinach, B. M. (2002). A cognitive strategy for developing prospective teachers' pedagogical content knowledge in the secondary mathematics methods course: Toward a model of effective practice. *Teaching and Teacher Education*, 18, 51 -71.
- Le Boterf, G. (1994). *Construire les compétences individuelles et collectives*. Paris: Editions d'Organisation.
- Lederman, N.G., Gess-Newsome, J. & Latz, M.S. (1994). The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. *Journal of Research in Science Teaching*, 31, 129-146.
- Leinhardt, G., McCarthy Y., & Merriman, J. (1995). Integrating professional knowledge: the theory of practice and the practice of theory. *Learning and Instruction*, 5, 401-408.
- Loughran, J. (2002). Understanding and articulating teacher knowledge. In C. Sugrue and C. Day (Eds.). *Developing Teachers and Teaching Practice* (pp.146-161). London: Routledge Falmer.
- Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting Science Teachers' Pedagogical Content Knowledge Through PaP-eRs". *Research in Science Education*, 31, 289–307.
- Loughran, J., Mulhall, P., & Berry, A. (2004). In search of the pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, 41, 370-391.
- Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam, The Netherlands: Sense Publishers.
- Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah: Lawrence Erlbaum.
- Mellado, V. (1998). The classroom practice of preservice teachers and their conceptions of teaching and learning science. *Science Education*, 82, 197–214.
- Park, S., & Oliver, J. S. (2008) Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education*, 38, 261-284.
- Perrenaud, P. (2000). *10 Novas competencias para enseñar*. Portoalegre: ArtMed Editora.
- Prosser, M., Trigwell, K., & Taylor, P. (1994). A phenomenographic study of academics' conceptions of science learning and teaching. *Learning and Instruction*, 4, 217-231.
- Sassi, E., Monroy, G., & Testa, I. (2005). Teacher Training about Real-Time Approaches: research-based guidelines and materials. *Science Education*. 89, 1, 28-37.
- Shön, D. A. (1983). *The reflective Practitioner: How professionals think in action*. New York: Basic Book.

- Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15, 4-14.
- Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57, 1–22.
- Simons, P.R.J. (1996). Metacognitive Strategies: teaching and assessing. In L.W. Anderson (Ed.). *International Encyclopaedia of teaching and teacher education* (pp. 325-342). Oxford: Elsevier Science.
- Sperandeo-Mineo R.M., Fazio C. & Tarantino G. (2006) Pedagogical Content Knowledge Development and Pre-Service Physics Teacher Education: A Case Study. *Research in Science Education*, 36, 3, 235-268
- Stofflet, R.T. (1994). The accommodation of Science Pedagogical Knowledge: the application of Conceptual change constructs to teacher education. *Journal of Research in Science Teaching*, 31, 787-810.
- Turner-Bisset, R. (2001) *Expert Teaching*. London: Fulton.
- van Dijk, E.M., & Ulrich Kattmann, B., (2007). A research model for the study of science teachers' PCK and improving teacher education. *Teaching and Teacher Education*, 23, 885–897.
- Van Driel, J.H., Verloop, N., & De Vos, W. (1998). Developing Science Teachers' Pedagogical Content Knowledge. *Journal of Research in Science Teaching*, 35, 673-695.
- Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, 38, 137-158.
- Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The Development of Preservice Chemistry Teachers' Pedagogical Content Knowledge. *Science Teacher Education*, 86, 572–590.
- Veal, W. R. (2002). Content Specific Vignettes as Tools for Research and Teaching. *Electronic Journal of Science Education*, 6, 4, <http://unr.edu/homepage/crowther/ejse/veal.pdf> .
- Verloop, N., Van Driel, J. H., & Meijer, P.C. (2001) Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research*, 35, 441-461.