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Relationships among cognitive and emotional knowledge of teaching quantum chemistry at university level

Kira Padilla[1] *and Jan H. Van Driel*[2]

ABSTRACT
The purpose of this paper is to identify and analyze relationships within and between the cognitive and emotional knowledge of teaching quantum chemistry as subject matter at the university level. The model of pedagogical content knowledge (PCK) of Magnusson *et al.* (1999) was used to study the cognitive dimension. Emotional aspects, included teachers' attitudes towards the difficulty and importance of certain topics, and teachers' feelings with respect to student learning were also studied. A sample of university professors ($n = 6$) from The Netherlands who taught quantum chemistry at the undergraduate level was interviewed. Data analysis combined a quantitative and qualitative methodology. Relationships were found between the cognitive subcomponents of the Magnusson model, between the emotional aspects, and between cognitive and emotional aspects of teaching quantum chemistry.

KEYWORDS: emotional and cognitive knowledge, university quantum chemistry, PCK

Resumen (Relaciones entre los aspectos emocionales y cognitivos de la enseñanza de la química cuántica en el nivel universitario)
El propósito de este artículo es identificar y analizar las relaciones entre los aspectos emocionales y cognitivos de la enseñanza de la química cuántica en el nivel universitario. El modelo de Magnusson *et al.* (1999) sobre conocimiento pedagógico de contenido (PCK) fue utilizado para estudiar la dimensión cognitiva. Los aspectos emocionales incluyen las actitudes de los docentes hacia las dificultades tanto de los estudiantes como de la misma asignatura y la importancia de algunos tópicos y de cómo se siente el docente cuando enseña esta asignatura. Se entrevistó a seis profesores holandeses universitarios que enseñan química cuántica a estudiantes que estudian alguna carrera relacionada con la química. Para el análisis de datos se utilizó una estrategia combinada cualitativa y cuantitativa. Se encontraron relaciones entre los subcomponentes cognitivos del modelos de Magnusson, entre los aspectos emocionales y entre los aspectos cognitivos y emocionales de la enseñanza de la química cuántica.

[1] *Corresponding autor.* Facultad de Química, Edif. "B" 2° piso 210, Universidad Nacional Autónoma de México, Delegación Coyoacán, 04510 México DF, México. Tel.: +52 (55) 5622 3711.
Correo electrónico: kira@unam.mx
[2] ICLON - Leiden University Graduate School of Teaching, Wassenaarseweg 62A; 2333 AL Leiden, The Netherlands. Tel.: +31 (0) 71527 4027
Correo electrónico: Driel@iclon.leidenuniv.nl
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Palabras clave: aspectos cognitivos y emocionales, química cuántica universitaria, PCK

Introduction

In research on science teaching, much attention has been paid to teachers' knowledge and beliefs (Abell, 2007). However, most studies concerned primary and secondary teachers; relatively little research has been done at the university level. Moreover, although it has been argued that emotions are at the heart of teaching (Hargreaves, 1998), there have been very few studies in the domain of science teaching that have taken the emotional dimension into account (Zembylas, 2004a, 2004b). The project reported in this paper concerned the teaching of quantum chemistry at the undergraduate level. Initially, the focus was on chemistry professors' pedagogical content knowledge (PCK) of quantum chemistry, gradually we became more aware of the importance for these teachers of the emotional dimension of teaching. Consequently, we broadened the scope of our study, seeking for relationships within and between cognitive and emotional knowledge of teaching this topic at the university level.

Framework

Pedagogical content knowledge

Since Shulman (1986) wrote the first definition of Pedagogical Content Knowledge (PCK), many researches related to this subject have been conducted (Smith and Neale, 1989; Kagan, 1990; Briscoe, 1991; Carlsen, 1993; Gess-Newsome *et al.*, 1993; Zuzovsky, 1994; Geddis, 1996; Adams *et al.*, 1997; Kennedy, 1998; Bond-Robinson, 2005; Park and Oliver, 2008). Some are focused on categorizing the knowledge that should be included in PCK (Cochran *et al.*, 1993; Stengel, 1997; Magnusson *et al.*, 1999; Hashweh, 2005). Others are more focused on trying to identify how teachers' PCK is being developed (Geddis, 1993; Clermont *et al.*, 1993; Lederman *et al.*, 1994; van Driel *et al.*, 1998; Loughran *et al.*, 2004; Goodnough, 2006; Major and Palmer, 2006; Nilsson, 2008). In addition, some studies have been conducted on the relationship between PCK and Subject Matter Knowledge (SMK) (McEwan and Bull, 1991; Foss *et al.*, 1996; Kahan *et al.*, 2003; Garritz y Trinidad-Velasco, 2006; Padilla *et al.*, 2008).

Shulman's proposal of what a teacher should know was focused on the "knowledge base" which was considered to consist of seven components: i) Content knowledge (or subject matter knowledge, SMK), ii) General pedagogical knowledge, iii) Curriculum knowledge, iv) Pedagogical content knowledge (PCK), v) Knowledge of learners and their characteristics, vi) Knowledge of educational context, and vii) Knowledge of educational ends, purposes, and values, and their philosophical and historical backgrounds (Shulman, 1987).

In the science education community, a well-accepted model related to what PCK should be, was elaborated by Magnusson *et al.* (1999). These authors claim that PCK is "a teachers' understanding of how to help students to understand one specific subject matter", and describe PCK as the knowledge that is acquired after a transformation from various sources of knowledge: subject matter knowledge, pedagogical knowledge and knowledge about the context. The combination of these three main sources leads to the formation of pedagogical content knowledge. According to these authors PCK has five components: 1) Orientation towards teaching science; 2) Knowledge of science curricula; 3) Knowledge of students' understanding of science; 4) Knowledge of assessment of scientific literacy, and 5) Knowledge of instructional strategies. In this proposal the last four components are all interrelated with the first one. Although in these PCK components almost all knowledge that science teachers should have is included, Magnusson *et al.* (1999) do not include subject matter knowledge per se, the one in which every teacher should be an expert, and as Gil-Pérez (1991, p. 72) said, "a good knowledge of the subject must include: knowledge about the history and philosophy of the subject, knowledge of the teaching methodologies, knowledge of the relationships among science-technology-society, knowledge about recent proposals or discoveries and to have some knowledge of those subjects related". As a resumé, in Table 1 we show four PCK's models taken from literature.

Many PCK researches are focused on secondary school, high school and pre-service teachers, only few of them have taken university professors as their object of study (Goodnough, 2006; Major and Palmer, 2006; Padilla *et al.*, 2008; Padilla and Van Driel, 2011). The necessity to study the pedagogical ideas and training of university professors was pointed out by Campanario (2002). He claimed that university teachers often have developed specific ideas and conceptions about what university teaching is, or should be. Mostly, these teachers do not have a pedagogical background, but they are primarily researchers, and as such, they are experts in the subject they teach. When they have to teach, they often do this in the same way in which they were taught.

In their paper about chemistry teachers' knowledge base, De Jong, Veal and Van Driel (2002) remarked the importance

Table 1. Different conceptions of knowledge.

Shulman's Knowledge Base[1]	Magnusson *et al.*'s PCK	Hasweh's TPC[2]	Pedagogical Knowledge[3]
Knowledge of educational ends, purposes, and values and the philosophical and historical grounds.	(1) Orientations towards science teaching.	Aims, purposes and philosophy.	Educational ends, goals, purposes and values.
Curriculum knowledge	(2) Knowledge and beliefs about specific curriculum.	Curricular knowledge.	
Knowledge of learners and their characteristics.	(3) Knowledge and beliefs about students' understandings of specific science topics.	Knowledge and beliefs about learning and learners.	Knowledge of learners and learning process.
	(4) Knowledge and beliefs about assessment in science.		Knowledge about assessment.
	(5) Knowledge and beliefs about instructional strategies in science.	Knowledge of resources.	Knowledge about instructional principles (models and strategies).
			Classroom Management and organization.
Subject matter knowledge.		Subject matter knowledge.	

[1] From this model we take apart the pedagogical content knowledge and the general pedagogical knowledge.
[2] From this model we take apart the pedagogical knowledge and beliefs.
[3] These components were taken from Morine-Dershimer *et al.*, (1999) from figures 1 and 2.

to develop chemistry teachers' SMK and PCK "in an integrated manner" and this would be particularly important for university professors. Studies on teaching chemistry at the university level have focused on the following subjects: chemical demonstrations (Clermont, Borko & Krajcik, 1994), physical and organic chemistry (Treagust, Chittleborough and Mamiala, 2003; Bucat, 2004), chemistry laboratory (Hofstein *et al.*, 2003, 2004; Bond-Robinson, 2005), amount of substance (Padilla, 2004; Padilla, *et al.*, 2008), chemical reaction (Reyes and Garritz, 2006) and most recently in quantum chemistry (Padilla and Van Driel, 2011). The present study will focus on the teaching of quantum chemistry at university level.

Teaching and emotions

Emotions are considered as the heart of teaching, because teachers are full of emotions all the time, and the cognitive scaffolding of concepts and teaching strategies is held together with emotional bonds (Hargreaves, 1998). In recent years, many researchers have focused on the importance of emotions in education. Some studies were focused on students (Pekrun, 2006; Ainley, 2006; Meyer and Turner, 2006), whereas others were more interested in the emotional dimension of teaching (Hargreaves, 1998; Zembylas, 2003; Zembylas, 2004a; van Veen *et al.*, 2005; Kelchtermans, 2007).

Emotions, mood, and affect are terms that are used interchangeably in research on emotions (Linnenbrik, 2006; Pekrun, 2006). The main difference among them is how long they last. Generally, moods are those kinds of portions of the affective domain which last longer but are less intense, and emotions are short, intense, and are considered to be a response to any particular situation (Zembylas, 2004a; Linnenbrik, 2006; Pekrun, 2006). Almost all researchers agree that emotions are consequence of the interaction between the individual and the environment (Hargreaves, 1998; van Veen, *et al.*, 2005; Zembylas, 2004a, 2007). Zembylas (2003) stated that many educational researches have focused on the rational dimension of teaching, that means teachers' cognitive thinking and beliefs, but there is not much research on teachers' emotions, because emotions are difficult to measure. Pekrun (2006) pointed out the importance of the links between emotions, cognition and motivation and their effects.

Sutton and Wheatley (2003) wrote a review of the literature on teachers' emotions, in which they explain that there are four kinds of emotional processes. The first one is due to some kind of judgment or *appraisal*, which depends on three factors: a) goal relevance, b) goal congruence or incongruence, c) ego-involvement. These three factors provoke that from the same situation, each individual has different emotions, and as Van Veen *et al.* (2005) said "appraisal involves an evaluation of the personal significance of what is happening during an encounter with environment". The second process is called *subjective experience of emotions*; this process depends on a private mental state and considers that emotions are felt different by each person. This process can be studied through metaphors because is a way to understand the experiences and pedagogies of science teachers (Zembylas, 2004b); for instance, during the process from anger to calming down, the first is related to fire or heat, and the second is related to cooling. The third process is connected with physical changes in the body, which means *physiological changes and emotional expressions*. The foremost is detected when we have changes of temperature, our heart starts to accelerate or when we have changes of pressure; the latter is more evident for other people because is it visible in our face through facial expressions. The fourth and last emotion process is called *action tendency* or *response tendencies.* These are considered so powerful, because they could temporarily over ride longer-term goals of emotional regulation. These tendencies are related to moods and attitudes during a lecture.

There are two main different kinds of emotions: positive, as happiness, or enthusiasm; and negative, as frustration, depression, or shame. Positive emotions involve pleasure or occur when one is making progress towards a goal (Sutton and Wheatley, 2003). There are different positive emotions associated with teaching, and the most studied are love and caring. However, other positive emotions are joy, satisfaction and pleasure which imply a progress in children learning. The most common negative emotions are anger and frustration, which come from goal incongruence and could be provoked by different factors as students' misbehavior, violation of rules and others factors that could make difficult to teach well (Sutton and Wheatley, 2003). These authors remark that these two negative emotions could be exacerbated by tiredness and stress, and could provoke shame.

PCK and emotions

Until now we have introduce a wide view of what has done of PCK and emotions research. However, we think that it is important to analyze what has been done related to the connections between both dimensions of teacher knowledge.

One of the first researches who analyzed the importance of emotions in the teaching practice was conducted by Rosiek (2003). He described the use of teachers' pedagogical knowledge "as analogies, metaphors, and narratives to influence students' emotional response to specific aspects of the subject matter in a way that promotes student learning" and this is what he has called "emotional scaffolding". Rosiek (2003) concluded that PCK has an emotional dimension, because students' emotions play a key role in the "transformation" of the knowledge that is considered as fundamental to PCK. Besides, he argued that many researches have showed that "cognition and emotion cannot be adequately understood as separate phenomena". This conclusion was supported by McCaughtry (2004) who also said that PCK does not depend just on cognitive knowledge, but teachers' decisions about how to develop the content, curriculum and pedagogy are influenced by how they interpret emotions.

Another study in this context was developed by Zembylas (2007), who said that one aspect of teacher knowledge that has not received special attention is its emotional dimension, "in particular how teachers understand the emotional aspects of teaching and learning". In this research Zembylas used the term "emotional ecology" saying that this concept has three planes that are related with three different types of *emotional knowledge*. The first plane is the Individual that is related with teachers' emotional connections to the subject matter (in some way we have included this plane in our subcomponents), attitudes and beliefs about learning and teaching. The second plane is the *relational* that is related with teachers' affiliations with students, students' own emotional experiences (this is also mentioned by Rosiek, 2003 and McCaughtry, 2004), which includes caring, empathy, classroom emotional climate, knowledge of students' emotions (this plane has been included in our emotional subcomponents). The third and last plane is the *socio-political* that is related with *emotional knowledge* of the institutional/cultural context (this plane is not included in our emotional subcomponents). Zembylas (2007) concluded that improving the emotional understanding of teachers can enrich their pedagogical understanding, and that teachers' emotional knowledge needs to be connected with the subject matter, the students, as well as the teachers' own experiences.

Finally, Garritz (2010) did a very interesting literature analysis where he looked for those connections between PCK and affective domain. Garritz shows how many authors have mention the necessity to study the affection domain in teaching-learning process. Some of these authors have demonstrated that "teachers love both their subject and teaching it" and even said that "if academics are to become better teachers, it must be built upon this love". To refer to emotional ecology or dimension, following Zembylas, we will use the term "emotional knowledge", which includes attitudes and feelings, since this term is conceptually related to PCK.

Research questions

In order to elucidate PCK about quantum chemistry from university teachers, we used the following research questions:

1. What is the content of the PCK subcomponents of experienced university teachers of quantum chemistry?
2. What kind of connections can be found between these PCK subcomponents?

After our first analysis we include the following ones:

3. Is emotional knowledge present in the quantum chemistry teaching-learning process?
4. What kind of connections can be found between PCK and emotional knowledge?

Method

Sample

As we have said before, the original main purpose of this research was to study the PCK of university teachers, specifically those who teach quantum chemistry at the Bachelor's level. To do that, we contacted ten teachers from different universities in The Netherlands. Six of them answered positively. The six teachers, besides to have an expertise in the subject, have been taught Quantum Chemistry at university level from 2 to 25 years. To preserve their anonymity we will use feminine pseudonymous. All of them teach very similar groups of students, from the first or second year of chemistry degree course (chemistry engineering, chemistry, etc.). Each group consists between 25 to 30 students and just some of them have what they call "lab work and workshops".

Procedure

We designed a set of questions related to basic concepts which are taught in quantum chemistry courses. These questions were related to components of the PCK model. Sample questions are:

1. What kind of ideas related to this concept do you think your students have before take this course?
2. What do you do to help your students to understand this concept?
3. When you make your planning class what kind of strategies do you use to catch students' interest?
4. What kind of strategies do you use to check students' understandings of this concept?

The first author interviewed each teacher individually, and the interviews (lasting from 45 minutes to one and a half hour) were recorded, transcribed and analyzed. The chosen concepts were: atom model, wave-particle duality and atomic orbital, because in the literature these are reported as basic ideas that should be understood by students because are fundamental to this topic (Martin, 1974; Warren, 1974; Jones, 1991; Johnstone, Crawford and Fletcher, 1998; Mashhadi and Woolnough, 1999; Gardner, 2002; Nakiboglu, 2003).

Analysis

To the analysis process was adopted a systematic procedure, which consisted of the following steps. First, the interviews were transcribed in full and the first author read the transcripts repeatedly to get an overview of them. Second, each interview was broken into different fragments (45 to 94). Fragments consisted of one or several lines that concerned the same issue or topic.

Next, to develop a coding scheme, we started with Magnusson's model of PCK, which consists of five components related to: orientations towards teaching science (A), teacher's knowledge of science curriculum (B), teacher's knowledge of students' understanding of science (C), teacher's knowledge of assessment in science (D), and teacher's knowledge of instructional strategies (E). For the purpose of this study, each of these components was divided into other subcomponents that go from two to nine. In this case we considered only those subcomponents that are important to university level[1] (see Table 2).

Moreover, after the first interview analysis we decided to add to our coding scheme three components related to teachers' attitudes and emotions, all of them related to those reported by Zembylas (2007) and Garritz (2010). The first one is teachers' attitude or feelings (both considered as emotions) towards teaching (F), which is divided in two subcomponents:

a) Positive or negative attitude towards the subject (F1), which is related with appraisal emotional process, because depends on what kind of judgment teacher do in relation with the subject,
b) Positive or negative attitude towards the teaching-learning process (F2) (see table 2), which is focused on teachers' attitudes or emotions as happiness, frustration, hope or things that they wanted or not to do during the lecture and that are related with moods and feelings.

Therefore, this subcomponent concerns teachers' *response tendency* (Sutton and Wheatley, 2003) because we considered that depends on teachers' perception about the teaching-learning process (both are in the individual plane of Zembylas (2007)).

The second emotional component is related to teachers' perceptions or attitudes about students' attitudes which is divided in two subcomponents:

a) Teachers' perceptions about how to improve students self-learning, and how teachers stimulated this process (G1);
b) Teachers' attitudes or feelings towards students' attitude in relation to their own learning, and ways of learning (G2).

These subcomponents are focused on what teachers think or do related to students' attitude; it means that teachers make a judgment about students' attitude or feelings and thus these subcomponents belong to *appraisal* processes (Sutton and Wheatley, 2003).

Finally, we added one more component which is related to teachers' attitude towards subject matter knowledge (SMK). Obviously, it is fundamental that teachers have a good knowledge of their subject, but teachers also have ideas about the importance of certain knowledge, what is fundamental and what is peripheral, what is confusing or attractive, and so on. We distinguished four subcomponents (H1-H4, see Table 2) and we think that these fit in the *subjective experience of emotions* process (Sutton and Wheatley, 2003) as well as what Garritz (2010) reports of teachers love subject matter and teaching; because teachers' feelings about SMK depend on how teachers perceive the SMK. All these added components are related to first and second planes of emotional ecology described above, because we introduce emotional connections to subject matter, attitudes and beliefs about learning and teaching, knowledge of students' emotions.

After several iterations, table 2 was developed as our coding scheme. This table was developed by both authors, by interpreting and discussing the content of selected interview fragments. In the next step, this coding scheme was applied to the interview data. As a result, a matrix of N fragments per 26 codes (see table 2) was developed. One first code analysis was made by the first author, and a second one was made by a research assistant, who was not an expert in quantum chemistry, but who specializes on education research methodology. To each fragment 1 to 4 codes were assigned, and the codes were compared and discussed until agreement was reached by the first author and the research assistant.

In the following step, we computed the relative frequencies of each subcomponent per interview and the frequencies in which pairs of subcomponents appeared together in each one. A data matrix per interview was introduced into PRINCALS[2] to reduce the data and to identify relationships among subcomponents. It was decided to delete those subcomponents with low frequencies (< 3%), prior to data introduction into PRINCALS. The information retrieved from PRINCALS is basically one graph for each interview, where

[1] For instance, in the subcomponent Orientations to Science Teaching, we noticed that quantum chemistry teachers never mentioned subcomponents as Inquiry, Discovery or Project-based Science and for that reason we decided to remove them from our model. Another important change concerns the definition of Knowledge of specific Curricular Programs; in Magnusson *et al.*'s model this subcomponent is related with changes of the curriculum more than with the knowledge of the curriculum per se. In our study, we decided to formulate this component just in terms of the knowledge of materials and curriculum, saying that the term materials is more related with books, or computational programs to solve problems and simulations.

[2] The PRINCALS methodology: in this case PRINCALS was used to explore the relationship among different subcomponents of PCK for each teacher. PRINCALS is essentially the same as Principal Components Analysis in that it allows calculating loadings for variables as well as scores for individual objects or persons, both with respect to the same dimensions. (Gifi, 1985, 1990) and is a kind of analysis which consist in the reduction of an original variable set in a smaller set of components which are not correlated among each other and that represent almost all information founded from the original set of variables. In this sense the categorical variables are quantified in a specifically dimensionality, as a result some nor lineal relationships among variables could be modeling. All statistical analyses were performed using SPSS software, version 14.1 [Note that in this version, PRINCALS is part of the optimal scaling techniques as 'Categorical Principal Components (CatPCA see Note 3)'; see also SPSS Inc., 1990: chap. 8].

Table 2. Components and subcomponents of PCK used in this research.

Orientation	Code	Definition	Example from interviews
Orientations toward teaching Science (A)			
Orientation	*Code*	*Definition*	*Example from interviews*
Process	A1	Teacher introduces students to the thinking process employed by scientists.	"I talk about the people of quantum mechanics, some of the excitement of the discoveries (A1). I try to give them perspectives on how unusual this development has been and what a great achievement, and also I stress a lot that it is an unfinished theory (A1)."
Academic Rigor	A2	Students are challenged with difficult problems and activities. Lab work and demonstrations to show the relationship between concepts and phenomena.	"I provide them a lot of exercises. So actually they have to do calculation on paper to write (A2) on the wave functions."
Didactic	A3	Teacher presents information through lecture or discussion, and directed questions.	"I try to explain what a particle is (A3), [...] then I focus in a couple of things that OK you can have interference so they also interact with each other in a certain way."
Conceptual change	A4	Students are pressed for their views about the world and consider the adequacy of alternative explanations. Teacher facilitates discussion and debates necessary to establish valid knowledge.	"…what we called [wave-particle duality] that is both or is not of them it is not really essential but they discovered that electron behavior is different (A4) that it is really some quantum mechanics about the electron."
Activity-driven	A5	Students participate in "hands-on" activities used for verification or discovery.	"We try to make the quantum world a live (A5) by a lot of paper and pencil work and this visualization (A5) is actually in the computer lab and the web package that's I do actually."
Knowledge of Science Curriculum (B)			
B1. Teachers' knowledge of goals and objectives	B1	Teachers' ideas of students' goals to learn that subject.	"If you do not understand this concept you cannot possible hope to understand the chemical bonding (B1). It is a key ingredient and I try they go to steps where we are on this map to work our final goal."
	B2	Teachers' goals and guidelines across topics .	"I'm trying every time to try out line on (B2) why, how is fixed in to the line of the course I have tried to out the whole course a kind of red line (B2) which I follow."
	B3	Students' knowledge acquired in previous courses or what they should learn to this or next courses.	"I think they heard about Bohr model in high school (B3)."
B2. Teachers' knowledge of specific curricular programs	B4	Knowledge of curriculum and materials related to the subject they teach and others related to this.	"In the book, (B4) there are some number of exercises in the back and some exercises with step by step explanations to help to solve a problem, calculate something but there are also part of questions which are to check the concepts."
Knowledge of students' understanding of science (C)			
C1. Knowledge of requirements for learning	C1	Prerequisite, abilities and skills to learn that concept and alternative conceptions.	"In essence, we don't spend too much time in doing learnt complicated derivations, but of course we do emphasize that it is a key point (C1) you have to be able to do it."
	C2	Variations in students approaches or views.	"I try to make connections back to their models (C2) and try to outline what is not complete in the relational model."
C2. Knowledge of areas of students difficulty	C3	Science concepts or topics that students find difficult to learn (abstract or lack any connection to students' common experience) or non intuitive.	"Once you are at the university and take quantum mechanics for the first time you really open these Pandora's box (C3)."
C3. Beliefs about what students know or not, or they should learn	C4	Teachers beliefs related to that knowledge that he/she assume or believe that students have or not; or that knowledge that teachers think students should learn.	"I think they have some notions of general chemistry (C4)… they have some notions of the wave concept of atomic orbital and what those concepts means."

Knowledge of assessment in Science (D)			
D1. Knowledge of dimensions of Science learning to assess	D1	Those concepts that are important or not to assess.	"I don't think it is necessary to test the atomic model (D1) in such as sense at the exam."
D2. Knowledge of methods of assessment	D2	What kind of strategies teachers use to assess students' understanding or those that they consider are not so good.	"I did test through exercises (D2) I've given them the opportunity to prove that they know it."
Knowledge of instructional strategies (E)			
E1. knowledge of subject-specific strategies	E1	Strategies that are more general and could be used to teach almost any subject. (e.g. learning cycle).	"Very often in the lecture I explain a concept and some practical results come up with them and then I ask crossed references (E1) back two, three or four lectures ago to see if they have acquired that knowledge."
E2. Knowledge of topic-specific strategies	E2	Topic specific representations (e.g. illustrations, examples, models, analogies).	"You can visualize (E2) and try to connect back to the equations."
	E3	Topic specific activities (e.g. problems, demonstrations, simulations, or experiments).	"Of course I provide them a lot of exercises (E3), so actually they have to do calculation on paper."
Teachers' attitude toward teaching (F)			
F. Positive or negative attitude or feelings towards teaching (response tendencies)	F1	Positive or negative attitudes towards SM that teachers wanted or not to teach or that helps to build up students' knowledge.	"I do not think (F1) one should spend too much time into that. I think that atoms are more like building blocks."
	F2	Positive or negative feelings related to teaching-learning process. Besides this component is related to teacher believes associated with the difficulty of the knowledge and think that students have to get used to it.	"To do that, in according to the web, were given also quantitative arguments and I am quite happy (F2)." "I tell them every time you don't worry about if they are confusing, it is perfectly natural that you are confused and you have to get used to these ideas (F2)."
Teachers' attitude towards students' learning (G)			
G. Teachers' perceptions or attitudes about students' attitude (appraisal)	G1	Teachers think that students should realize that good learning is their own responsibility.	"They also should realize (G1) that most of the interesting realistic problems can be solved only with the help of computers, even very powerful computers."
	G2	Teachers' attitudes or feelings about students' perceptions or feelings towards their own learning.	"I don't mind (G2) if they remind a little bit wave or undiscovered it is more like a feeling that if they want to work with their understanding this is not something that you could put in a box."
Teachers' attitude towards subject matter knowledge (H)			
H. Teachers' ideas or perceptions related to the subject they are teaching (subjective experiences)	H1	That knowledge that is important to know but it is not necessary to teach.	"I have to really sacrifice things (H1) trough up black body radiation because it is not essential to get the chemical bonding."
	H2	i. That knowledge that is confuse for everybody. ii. That knowledge that is considered difficult to teach or to start with.	"This particular idea of having electrons how is their particular behavior that makes atoms to find the bonds, nobody really knows (H2) how to think about it properly."
	H3	i. That knowledge that is classified as fundamental to understand this and other subject. ii. The difficulty to comprehend the physics behind mathematical equations.	"In essence, we don't spend too much time in doing learnt complicated derivations, but of course we do emphasize that it is a key point you have to be able to do it (H3)." "Why is the momentum associated to $-i\hbar d/dx$ operator, so the difficulty is not the mathematics by itself, it is not so difficult but has to be loaded with a lot of meaning (H3) when you talk about quantum mechanics."
	H4	i. That knowledge that had been learnt in other courses but teacher thinks it is wrong. ii. That knowledge that is rudimentary and attractive to students.	"I mean, a lot of people teach bonds between atoms as being as electron pairs and then said pairs of electrons are attracted by both nuclei; that is not a very correct picture (H4)." "They know perfectly well that it is primitive (H4) that quantum mechanics is much more suitable."

Some parts of this table were taken from Padilla and Van Driel (2011).

Table 3. Relative frequencies (percentages) of each subcomponent to each teacher.

	A1	A2	A3	A4	A5	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	E1	E2	E3	F1	F2	G1	G2	H1	H2	H3	H4	
Tanja	0.7	0.7	5.0	0.0	0.0	0.0	0.0	2.2	4.3	7.9	2.9	5.0	3.6	2.9	3.6	2.9	4.3	5.8	9.4	8.6	2.2	16.5	0.0	0.7	3.6	7.2	100
Pauline	0.0	3.2	4.6	0.3	0.6	2.0	6.3	2.6	4.6	4.6	2.0	2.0	0.9	3.2	3.2	5.8	1.7	4.3	10.1	11.0	6.1	8.4	5.2	1.4	4.3	1.7	100
Maya	0.9	2.3	7.3	0.9	0.0	1.4	3.7	3.2	6.9	6.4	0.5	2.3	4.6	1.8	3.2	5.5	2.3	5.5	10.6	6.4	0.9	11.0	2.3	3.2	6.4	0.5	100
Irene	2.1	1.4	9.9	0.0	0.0	2.1	2.1	6.3	7.7	4.2	0.0	4.9	3.5	1.4	1.4	3.5	1.4	3.5	7.0	7.7	2.8	8.5	3.5	4.9	6.3	3.5	100
Patrice	0.0	4.8	7.0	0.0	1.6	3.8	1.1	2.2	4.3	5.4	0.0	5.4	2.2	0.5	2.2	3.8	7.5	4.3	9.1	5.4	2.7	10.8	1.6	1.6	7.5	5.4	100

those subcomponents that appeared in the interview are shown as arrows. These arrows have two specific characteristics: first the longer they are, the better they fit in the general solution; second, the smaller the angle between them, the more interrelated they are; which means that they have high correlation. With this information we could make a specific analysis of each graph, and found clusters of two or more interrelated subcomponents that characterized a teacher's PCK including their emotional knowledge. Finally, results from each teacher were compared and discussed (Part of this text was taken from Padilla and Van Driel, 2011).

The same process was applied for each teacher. It was decided to not use one of the six interviews, because the analysis did not reveal a clear picture. Finally, we compared the results from the different teachers.

Results

In table 3 the relative frequencies for each subcomponent are presented. In this table we could observe that not all subcomponents are used by all teachers. We will discuss each case individually and then we will proceed to make an overall analysis.

In table 4, we present the frequencies of different pairs of subcomponents for each teacher. These frequencies were obtained by counting how many times each pair of components in the interview appeared in the same fragment.

Pauline

Pauline's interview was the longest in time and information. We could obtain 94 fragments to classify. The PRINCALS graphs (figure 1.a) show four important pairs of components. These are: A2-E3, F2-G2, G1-H1, B4-F1. All these pairs have a good correlation and fit very well in the whole solution, besides have a good frequency of intertwine (see table 4). Each pair will be discussed individually. The first pair of components is F2-G2 is related with the emotional part of teaching. In this case the interview contained phrases like the following:

> "I'm not being able to force them (G2) to be interested, but I try that the way I teach would be enthusiastic and lovely (F2)…"

This sentence is a clear example of these two subcomponents. The first part represents G2, because Pauline is talking about students' interest during the lecture. With this idea Pauline could have expressed that students' interest on subject depends not just on students' attitude but even in the way she use to teach the subject and her own attitude in the lecture. Besides, this is a clear example of the emotional knowledge of teaching (F2), because she tries to be more 'enthusiastic and lovely' with his students. The second pair of subcomponents is B4-F1; this pair relates the teacher's knowledge about curriculum and materials, to the teacher's feelings about the subject. This is the first pair which related cognitive and emotional dimensions of teaching. In this case, this pair has a good fit, good correlation and good frequency, which could mean that to Pauline, this combination, is quite important for her teaching. In the next quote, Pauline shows how important it is to her to make cross references through the whole course to enable students to build their knowledge:

> "I cross references to back (B4) all to the first lecture and I try to do that all the time. That is what I do during the lecture to try to have the key point on my red line in mind; I try to cross references back because it is a pretty efficient way of building knowledge (F1)."

Another pair of subcomponents is A2-E3, we think that the relationship between these two subcomponents is quite clearly illustrated in the following fragment:

> "…the combination of direct interaction with students, and providing them challenging exercises (A2, E3) and checking if they have understood the key concepts…"

Table 4. Pairs related to each teacher and theirs frequencies of intertwine.

Pauline		*Patrice*		*Irene*		*Maya*		*Tanja*	
A2-E3	8	A1-E3	4	B3-C4	7	B2-F1	9	C2-F1	4
F2-G2	13	F2-G2	7	F2-G2	4	F2-G2	12	F2-G2	11
B4-F1	12	A2-E1	4	B4-C4	5	B4-C4	6	E1-G1	3
G1-H1	8	B4-C1	5	F1-H2	5	A3-D2	5	C1-C4	5
B3-C1	4	C1-H3	4	E3-H4	2	B3-C1	4	D1-D2	2
A3-E1	6	B4-H3	4					E2-E3	3
		D2-E3	4						

Relations between cognitive and emotional subcomponents are highlighted in bold type.

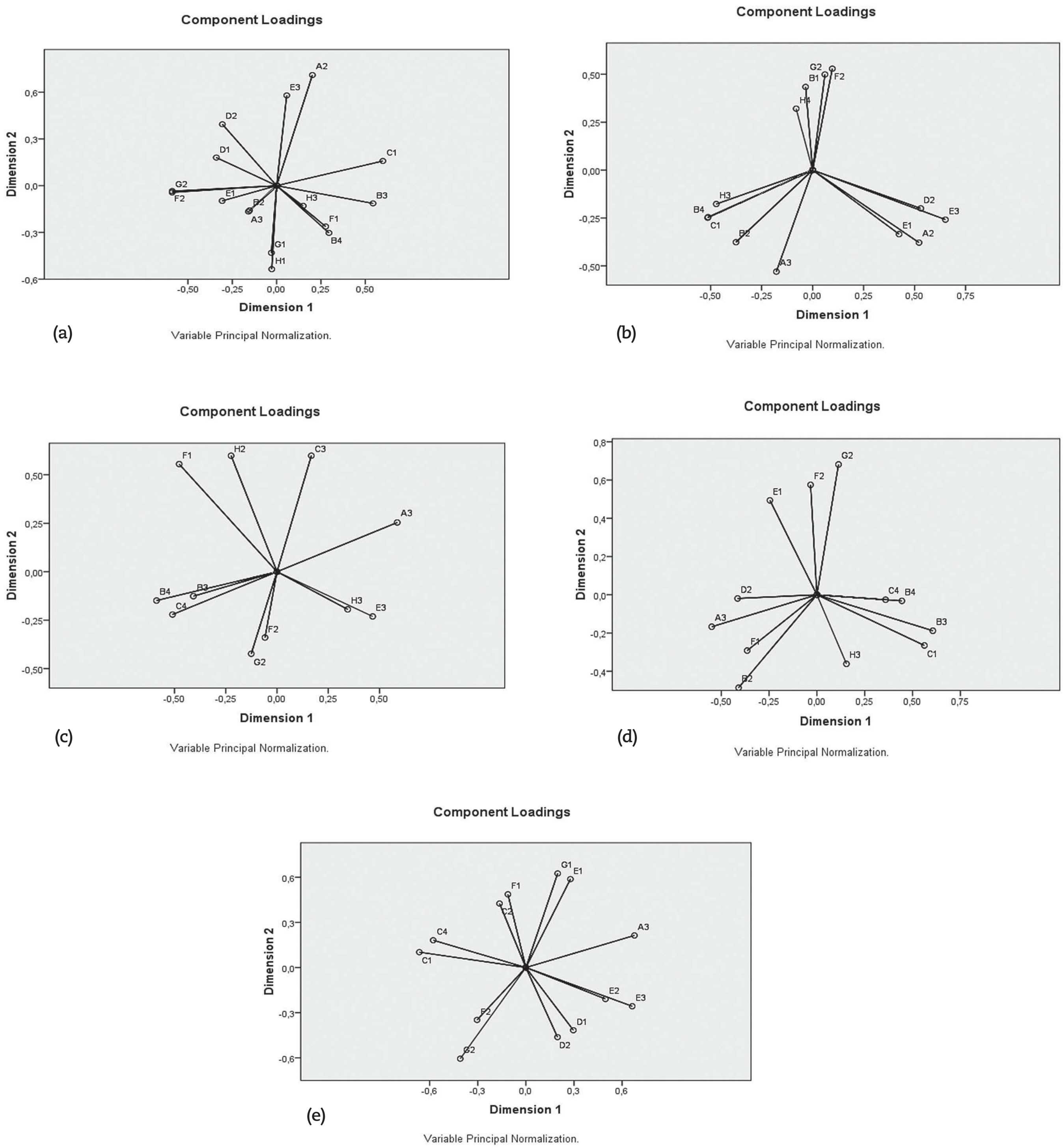

Figure 1. Graphs got from PRINCALS analysis:[3] (a) Pauline; (b) Patrice; (c) Irene; (d) Maya; (e) Tanja.

[3] Principal component analysis (PCA) is a well-known and efficient technique for reducing the dimension of a high-dimensional data. PCA forms new 'variables', called principal components, which are linear combinations of the original variables in such a way that are uncorrelated and the vector of coefficients (or loadings) are orthogonal. Cluster analysis is an exploratory statistical technique concerned with grouping items into homogeneous 'clusters' on the basis of some kind of similarity/dissimilarity data.

The fourth important pair is G1-H1. In the following example, Pauline is talking about the historical evolution of quantum mechanics. She comments that although this is an important topic, she could not spend too much time on it and left students to read about it if they are interested.

> "I leave them to their responsibility to do additional reading (G1), even in a textbook which I provide them or I left them to use other mediums. I try to make a small, but important historical moment to give a short account of it (H1) and then I just tell them go and read about your self if you are interested… We don't have time to do all these steps in history, to follow the evolution, because I could do that and I beloved to do that, but we do not have enough time."

One pair of components that was also interesting to analyze, although it does not have a good correlation and a good fit in the Princals results, is A3-E1. In the following paragraph Pauline is explaining how she is used to introduce the wave-particle duality idea:

> "I try to explain of what a particle is, and then I spend some time on the waves and explain all we know about the diffraction of waves (A3) to deduced this experiment (double slit experiment). Then I focused in a couple of things that, ok you can have an interference so they also interact with each other in a certain way (E1)."

The last pair that we will analyze from this interview do not have a good correlation or frequency, but has a good fit in the whole solution, this is: B3-C1. This pair implies that the previous curriculum is quite related to those ideas that could be useful as a learning tools to build the framework knowledge, but at the same time could be an obstacle to get a good learning process:

> "Some [students] have mini term solar system in mind (C1). I think that it is what basically they have from high school (B3). If they have any model atom, it is the nucleus as a sun with electrons as a planets running around in orbits (C1)."

Summary

Pauline has four important relationships among the subcomponents. Three of them are close related with the emotional knowledge of teaching quantum chemistry. In the most relevant pair of subcomponents, Pauline relates his own feelings towards the teaching process with the students' attitude; the second shows the relation between Pauline's orientation towards teaching, and the kind of strategies that she uses to choose.

Patrice

In the case of Patrice her interview was classified in 72 fragments that were analyzed in a qualitative way and the data matrix was introduced in the PRINCALS program. From this analysis we obtain the graph (1.b) where we got the pairs of subcomponents that have a good correlation and fit well in the whole solution, we found basically the following: A2-E1, G2-F2, A2-E3, B4-C1 with the frequency showed in table 4. In this case we will start with F2-G2 pair which appeared to be important for all teachers in this study. In this case the kind of phrase that we found is:

> "I hope to transmit the enthusiasm with which I look at quantum mechanics (F2) as a fundamental theory to understand nature and […] I hopefully try (F2) to transmit this enthusiasm for the subject. I think is friendly when the atmosphere can help and also stimulating as much as possible the dialogue with students (G2)."

Another interesting combination of subcomponents is A2-E3, which appears in Pauline's interview as well. We can understand why these subcomponents fit together, because A2 reflects a way of teaching focused on problem solving and lab work and E3 reflects the topic strategies using principally problems, exercises, simulations, etc. and this relationship is reflected on the interview as follows:

> "They [the students] have to show, in the blackboard, to solve problems (E3), so every one can really contribute to this practical session (A2), not just with the teacher in front of and solving the problem for them."

Another relationship is the A2-E1 which shows that lab work or to solve problems and activities could be used as general teaching strategies, as we can see in the sentence below where teacher is talking about these two components:

> "I think that at very basic levels one needs to combine the traditional theoretical lecture also with computer lab, exercises (A2)… the combination with visualization and computer lab can be a very positive strategy (E1) for interest of them."

A final quite interesting pair is that formed by B4-C1 which has a perfect correlation and a perfect fit. B4 shows the teacher's knowledge about curriculum and materials, and C1 shows teachers' knowledge about students' prerequisite, abilities and alternative conceptions, as in the next paragraph is showed that teacher thinks that students need a good level of mathematics as a prerequisite to develop some skills in the subject.

> "I think mathematics should be teaching in a good level at the very beginning in the first year (B4) in order to prepare the student also to deal with differential equations, imaginary objects, matrices (C1)."

Summary

If we wanted to draw a teacher's profile of Patrice, we could say that this profile may depend on three main pairs of subcomponents. The first one is the teaching orientation and teacher's strategy; the second one is teachers' feelings to her subject and her perception towards students' attitude; and the third one is his knowledge about curriculum and how this influences the skills, abilities and preconceptions of students.

Irene

Irene's interview was classified in 51 fragments. The PRINCALS graph (1.c) revealed five pairs of sub-components that have or a good correlation or fit well; their intertwined frequencies are shown in table 4. The first pair to be analyzed is B3-C4, which besides they do not have a good fit (i.e. small arrows in figure 1.c), at least have a good correlation and a relative high frequency. One example of this relationship in this interview is shown below:

> "I tell them 'now we are going back to something that you know (C4), if you don't know, get your mathematics books of last year (B3) and look up second order of differential equations with constant coefficients. I'm going to do it but I know that you should already know how to do it'."

In this fragment, Irene assumes that students already know how to solve differential equations, because she knows that they should have already studied it in previous courses. This explains why she said that if they do not know (some mathematics ideas) they should look again at their mathematics books. The second pair that could be identified is B4-C4, again the teachers' beliefs (C4) about students' knowledge is present, but in this time is related with the teachers' knowledge about curriculum and materials (B4). We think that this two pairs (or one trio B4-B3-C4) should be interrelated, because it seems quite logical that teacher's beliefs about the knowledge that students should know or not, is linked with teachers' knowledge about curriculum and materials and about what students have learnt in previous courses. To the latter pair, we present one example from the interview.

> "They have learnt the concept already in the first year (B4). I'm teaching in the second year and in the first year they already know it (C4). Actually, it is even called chemical bonding. They get it without quantum mechanics, basically."

In the phrase above Irene is talking about one concept that students already know, but not through quantum mechanics. She is showing that she has knowledge about the curriculum and about those subjects that are related to the one she is teaching. Besides, she is assuming that students have already understood this concept. The third pair is F1-H2. Despite that this pair does not have a good correlation, it has a good fit and the frequency in the interview is relatively high. One example of a phrase from the interview is shown below:

> "I think that it is not possible to understand this idea, because it is not clear (H2). It is not a clear model, and this is something unfortunate (F1)… because understanding is hard."

In this fragment when Irene said that it is unfortunate that the model would not be clear, she is showing feelings of sadness, because she holds the belief that to students to get an understanding is not so easy, but if models are not clear for all, they will be difficult for students. The fourth pair is one that has been present in the previous interviews, that is, F2-G2. In this case, it does not have a good fit, but has a good correlation, and the frequency is relatively high (4). As we have already discussed the relationship between these two subcomponents, here we just show one of the phrases said by Irene:

> "I do this just to make them feel comfortable (G2). I don't know if they appreciated but I hope (F2) they are do convinced that we don't have two worlds…"

Summary

In the case of Irene we could identify three main relationships among subcomponents. The first one relates her feelings and beliefs towards her subject to students' attitude; the second one relates the knowledge of curriculum with her own assumptions about what students would or would not know; and the third one relates her perceptions about the SMK to the kind of instructional strategy or to her attitudes towards teaching.

Maya

The interview of Maya was divided in 72 phrases, and then analyzed. The PRINCALS graphic (1.d) and table 3 show at least five pairs of subcomponents which comply with, at least, two out of three conditions to be considered: fit well in the whole solution, has a good correlation, or good frequency. As we can observe the pair F2-G2 again has a good frequency and a good fit. It seems to be important to Maya, as for the other teachers in this sample. In this case we have chosen the next phrase to illustrate this pair:

> "I think they forget (G2) about sixty percent of [what] we teach them, because quantum mechanics is by… in that sense is quite unique course because it takes time to get used to the concepts (F2)."

In this phrase Maya thinks that students would forget almost all the course, which we think is a common thought about students' attitude towards any subject. At the same time she thinks that as quantum mechanics is a 'quite unique' course, after a while, students have to get used to it, or to the concepts that are taught (F2), which is clearly a *response tendency* because teacher is almost resigned to that students' oblivion.

The next pair is F1-B2 which has a good frequency and fit, but not a very good correlation, and relates cognitive and emotional dimensions of teaching. This pair relates teachers' goals (B2), and teachers' feelings about the subject (F1). For instance, in the phrase below Maya has cleared that do not make too much emphasis on mathematics, in spite of it is an important skill that should be developed to have a better understanding of this subject.

> "I think that our main strategy is to not confuse them with too many mathematics. That's the main goal (B2) what we do this year. We try to emphasize (F1) the concepts and not the mathematics."

The third pair that we found in Maya's interview is B4-C4, was apparent in Irene's interview as well. In this case, this pair has a very good correlation, a good frequency, but not so good fit. The following phrase is an example of this pair:

> "They all have seen them before in previous classes (B4). I think (C4) they know these strange shapes. I think (C4) they also know that there are core electrons and valence electrons…"

In the phrase above Maya is talking about some concepts that she thinks students have studied in previous courses, specifically General Chemistry, and that is for him the main reason to believe that students know something about it. The following pair has not so good correlation or fit but has a relatively good frequency. Besides, it is a pair that we did not find with the other teachers: A3-D2. In this case, Maya talks about how to assess students understanding during the lecture by asking students about the concepts. If these were not well understood, she did not say that she would use a different strategy to make students comprehend the concepts; she just said that she would try to explain these concepts in a different way, which could mean with different words. The following phrase is an example of her view:

> "Sometimes you explain something (A3), and then you stop a while then you ask a question about it to check (D2), and some times you notice that they did not understand it at all. So, you have to start again and try to explain in a different way (A3)."

The last pair that we found in this interview was B3-C1. This pair appears in Pauline's interview as well, but in that case the correlation was not so good. In Maya's case we have a good correlation and fit, but the frequency is rather low, compared to F2-G2. The following is a clear example of Maya's ideas:

> "I think they heard about Bohr model in high school (B3). They also discuss the Bohr model, even a little bit of quantum mechanics very basic, so in that sense it is not entirely new when they come here (C1)."

Summary

We consider that to Maya, as the previous teachers, there is one relationship that is particularly important: teachers' attitude towards teaching with teachers' perceptions about students' attitude. Besides, there is one more pair which appears in the others: knowledge of curriculum with knowledge of students understanding. The third important pair is between the curriculum knowledge (goals and guidelines) and teachers' feelings (positive or negative emotions) towards teaching.

Tanja

The interview of Tanja was divided into 46 fragments. The PRINCALS graph (1.e) shows the pairs of subcomponents that have a good correlation, and fit well in the whole solution; the frequencies of these pairs are shown in table 4. What we observe from this data is three pairs of subcomponents that belongs to the same main component; for instance, two components who belong to teacher's knowledge of students' understanding (C1-C4) have a very good fit, and correlation. The same happens with two subcomponents that belong to assessment (D1-D2) and to two that belong to instructional strategies (E2-E3); these relatiosnships were analyzed in Padilla and Van Driel (2011). In this research, other teachers show this kind of relationship as well, but apparently they are not as important as in this case. In addition to these three pairs, we have others that do not belong to the same main component. These are: F2-G2, C2-F1, E1-G1. The first one has appeared in all the other interviews, and in this case has a good correlation and frequency, but do not fit very well. The following example illustrates this pair:

> "If students realize that it is not always correct (G2), I'm already quite happy (F2)."

The pair C2-F1 relates two different subcomponents. In this case, the correlations, fit and frequency are good. One example of this pair is shown below, where Tanja is explaining that students usually bring up the idea of an atom model in terms of classical mechanics, and she said that they (students) have to realize that there is more than that simple model, which could means that students would change their views about the idea of an atom. Then she said that she does not mind that 'classical analysis', which is a specific attitude (F1) towards the subject.

> "If they realize that it is a simple picture (C2) that is actually not completely correct, I think that it is already quite an achievement if they see that. So, I don't mind simple classical analysis (F1), but as long students realize that there is more then (C2) I'm already quite."

The last pair is E1-G1; it has a good correlation and fit, but low frequency. It relates the general strategies used by the teacher (E1) and what she thinks or does to promote students self study (G1). Her main strategy is to promote students to become aware of their knowledge, which means that she uses a specific strategy to encourage students to become conscious about what they are learning (in this case the wave-particle duality).

> "You have to first make them realize that there is a problem with classical mechanics (G1). Through the example of photoelectric effect, that's one of examples that we use to show seeing that classical mechanics goes wrong (E1), and it is a nice example because you can show that something goes wrong and that actually should have also particle kind of nature."

Summary

The case of Tanja is particularly different from the others. This is because it seems that relations among subcomponents which belong to the same main component have more relevance for this teacher. However, at the same time, there are three other relationships; in two of them there is a dependency between teachers' attitude towards teaching and the one who relates students' attitude to the instructional strategy.

Discussion

In the present research we were initially focused on the study of the relations among PCK subcomponents. However, we had to acknowledge the importance of the emotional knowledge of teaching subject matter (i.e., quantum chemistry) and thus also investigated the relations described above. So, it is interesting to notice that there is one pair of subcomponents which appears to be important for all teachers. This is F2-G2, which shows the relationship between two emotional subcomponents. We think that this is interesting because it shows that these teachers are interested not just in the subject, but in their own attitude towards their teaching and the perception that they have about students' attitude, which seems quite important for their performance as a teacher. Irene gave us a clear example of these intertwined subcomponents:

> "If I notice that students get interested, I become much better as a teacher; because I like that and I start to talk more about other things. If students demonstrate how bored they are, then also I become worst as teacher, because I start to stick just the lecture notes and just tell them what they need to know and I feel less happy than when audience was receptive…"

It is clear that even in subjects as difficult as quantum chemistry at university level, the students' attitude could have a big influence on teachers' way of teaching, and on teachers' attitude towards the subject and towards students. For example, it is interesting to notice how Irene is worried about students' attitude and how his own attitude changes when she has a receptive audience or not, this process is clearly a *response tendency*. At a more general level, it is noteworthy that attitudes and emotions appear to be quite important for these university teachers. Many researchers have reported that the emotions of elementary or secondary teachers are influenced by the context (family parents, school authorities, students behavior, etc.; see Hargreaves, 1998; Zembylas, 2003; Zembylas, 2004a; van Veen *et al.*, 2005; Pekrun, 2006; Ainley, 2006; Meyer and Turner, 2006; Kelchtermans, 2007); however this hasn't been reported about university teachers.

In addition to this relationship between affective subcomponents, we found two important cognitive relationships. These are among the orientation toward teaching and instructional strategies (A-E); and knowledge of curriculum and knowledge of students understanding (B-C). The first one, A-E, appears in two of the five interviews, and we have said that this relation would be quite natural, because generally, the strategies used to make students learn a specific idea or concept, would normally depend on a teachers' orientation towards teaching. The second pair appears in four of the five interviews, and shows the relationship among teachers' knowledge of curriculum and their knowledge of students understanding. Again, it seems plausible that teachers need to have some knowledge of what kind of concepts have previously been taught to students, to comprehend much better students' understanding before and after they take a certain course. We also noticed that these two cognitive components (B-C) are often related with one emotional component, that is, teachers' attitude towards teaching, specifically with positive or negative attitude towards their subject (F1). These relationships are presented in three of the five interviews, which we think is quite comprehensible because, what a teacher wants to teach, or what he thinks should be taught, could easily depend on his own knowledge of the curriculum and students' understanding.

Finally we found cognitive-emotional relationships. In particular, these are between teachers' perceptions related to the subject (H) (the first plane of Zembylas (2007)) and three cognitive components: knowledge of curriculum (B); knowledge of students' understanding (C); and knowledge of instructional strategies (E). Teachers' perceptions of the subject requires from the teacher a deep knowledge of the subject, per se, but at the same time a very good knowledge about the instructional strategies, the curriculum and students' understanding. This means that teachers' moods and emotions about the subject often have a relationship with their (cognitive) ideas about the same subject, related to the curriculum, students' understanding and teaching strategies.

In figure 2 we can see the profiles of each teacher. It is important to remark that emotional components are quite important to all of them as well as D component is not as important as should be because is the component related to how they assess students learning. For Tanja C component is the most important as well as A and B are not as important in her profile. For the others teachers B component has more weight.

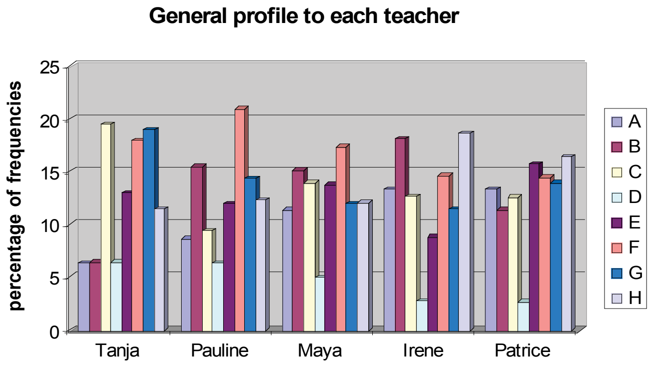

Figure 2. General profile showed for each teacher where we can see that beside of teching the same subject all of them have different profiles.

Conclusions

This research showed that there are relationships among the cognitive and the emotional dimensions of teaching subject matter. However, the results presented here are not conclusive to say that the emotional knowledge of teaching should be part of PCK. We believe that it is necessary to develop more research on this subject. Nevertheless, what we found is that there is a fundamental relationship among these two types of knowledge, and that they mutually influence each other. Since we also found a clear relationship among specific emotional components, we conclude that it is important that research on teachers' conceptions pays more attention to the emotional knowledge and its influence on teacher development. Using the Magnusson model as a starting point to our study, we have found teachers' emotions are clearly related to their PCK and SMK. Consequently, we have modified the model from Magnusson *et al.* (1999) according to our findings, putting emotions on the top of a tetrahedron, which could influence subject matter knowledge, pedagogical content knowledge, pedagogical knowledge and knowledge and beliefs about context (see figure 4). We could think that if there is an influence of teachers' emotions on the two former, there could also be an influence on the two latter. This is something that we left open because the data from our study do not allow us to draw a conclusion on such relations.

Whether emotional knowledge is a part or not of PCK is yet a question for future research. Besides, many authors have showed the importance of emotions in the development of teachers' PCK. This is influenced, among others, by the teachers' feelings and attitudes about their own way of teaching, the subject matter they are teaching, and their knowledge related to the attitude that students could adopt when students are learning that specific subject. These topics are related with teachers' emotions about their own practice.

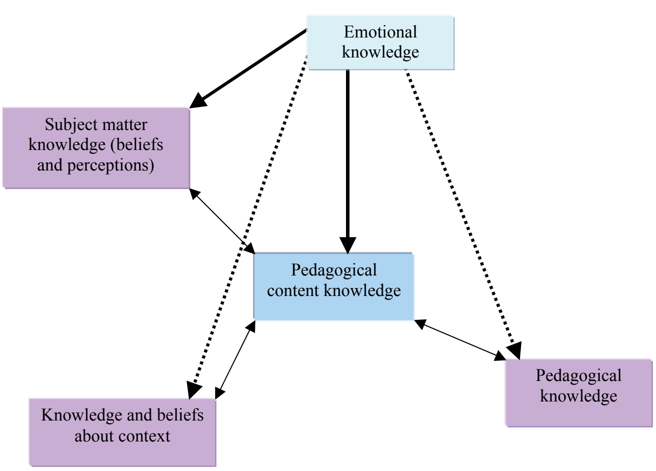

Figure 3. Model of relationships among the domains of teacher knowledge (modified from Magnusson *et al.*, 1999, p. 98).

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