INTERVIEWS AND CONTENT REPRESENTATION FOR TEACHING CONDENSED MATTER BONDING. AN AFFECTIVE COMPONENT OF PCK?

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Abstract

Pedagogical Content Knowledge (PCK) of four General Chemistry College professors on the topic of condensed phase substances' bonding models has been documented by Loughran *et al.* Content Representation (CoRe) and an interview in which some questions related to the affective domain of teaching were included.

In the introduction of this study the components and mechanisms of affective knowledge and its neurological foundation are analyzed.

The central ideas related to the CoRe were discussed with the four professors, arriving to the following four consensual central ideas:

a) Physical properties;
b) Bonding parameters (dissociation energy and distance);
c) Polarity and intermolecular interaction in covalent bonding;
d) Networks (metallic, ionic and covalent).

The professor faces a problem in the General Chemistry course when lecturing bonding in solid or liquid substances, because there are several bonding models applicable:

1) Covalent molecular bonding.
2) Ionic bonding.
3) Metallic bonding.
4) Multidirectional covalent bonding.

The CoRe sentences of the four professors were classified in four Mortimer's conceptual profile zones: conceptual, contextual, representational and procedural. It is concluded that the «network» concept may play a useful proposition to describe the last three bonding models and the professors can display it pretending students' conceptual comprehension of the topic.

It is interesting to say that all of them mentioned ways of achieving motivation and interest related to the specific topic, that is, what can be considered as a new element of PCK of the affective type.

Key Words: PCK, condensed matter bonding models, affective knowledge

Introduction. The affective domain of cognition

Our understanding of the neurological mechanisms by which humans acquire and retain knowledge has advanced a lot in recent years. In particular, the role of emotion in knowledge construction is being revealed in the two last decades not only within its psychological facet (Pintrich *et al.* 1993; Sinatra 2005), but also in the neuro-scientific one (Damasio 1994; LeDoux 1996; Panksepp 1998; Rolls 1999; Dolan 2002) and it is now clear that emotions, beliefs, attitudes, motivation and other types of affective knowledge, are intimately entangled with, and inseparable in education from "concrete" (e.g., semantic and scientific) knowledge (Southerland *et al.* 2001; Goswami 2006).

It has recently happened that teachers are encouraged to attend courses on brain-based learning. These courses suggest, for example, that children should be identified as either «left-brained» or «right-brained» learners, because individuals «prefer» one type of approach. Teachers are told that the left brain dominates in the processing of language, logic, mathematical formulae, number, sequence, linearity, analysis and unrelated factual information. Meanwhile, the right brain is said to dominate the processing of forms and patterns, spatial manipulation, rhythm, images and pictures, daydreaming, and relationships in learning. Teachers are advised to ensure that their classroom practice is automatically 'left- and right-brain balanced' to avoid a mismatch between learner preference and learning experience. All these have to do with student's learning styles (visual, auditory or kinaesthetic; Honey & Mumford 1982).

Over the past decade there has been a remarkable explosion of research on the neural substrates of affective processing (Davidson *et al.* 2003; Vilarroya & Forn 2007). Historically, emotion and cognition have been viewed as separate entities. The last view of brain organization supported the notion that there was a considerable degree of functional specialization and that many brain regions could be conceptualized as either 'affective' (as the amygdala, "the nucleus of fear processing"; Pessoa 2008, p. 149) or 'cognitive' (as prefrontal or parietal cortices). But now it is clear that complex cognitive–emotional behaviors have their basis in dynamic coalitions of networks of brain areas, none of which should be conceptualized as specifically affective or cognitive. This is the case for the Lateral Left Prefrontal Cortex (LPFC; Gray and colleagues, 2002). Evidence for cognitive–emotional integration in the LPFC comes from working memory studies involving the maintenance and updating of information, for instance, when participants were asked to keep in mind neutral or emotional pictures (Pessoa, 2008, p. 150).

> I propose that emotion and cognition are only minimally decomposable in the brain, and that the neural basis of emotion and cognition should be viewed as strongly non-modular. (p. 148)

McLeod (1992) suggests that beliefs, attitudes and emotions should be important factors in research of the affective domain in Mathematics Education. Those terms are used to describe a wide variety of affective responses specific to mathematics: beliefs about mathematics, beliefs about its teaching, attitudes toward mathematics and emotions (like tension and frustration in problem solving, or positive responses accompanying a moment of insight, see for example Liljedahl 2005). Gregoire (2003) has also detailed the affective components of cognition in Mathematics. All of McLeod and Gregoire's ideas can be perfectly poured into science education. And that is what this presentation would like to study: if there are items of the affective domain that are displayed on the teaching of a specific topic of university level's chemistry education, namely, chemical bonding.

Marina (1998), an Spanish philosopher says that it is necessary a generic term to describe all experiences related with an evaluation (please or unpleased, attraction or rejection, preferences)

and is inclined to «affectivity», «affect», or «affective phenomena» which imply the following denominations:
Affect; is the set of all experiences that have an evaluative component (painful-agreeable, attractive-repulsive, pleasant-unpleasant, good-bad, stimulating-depressing, activator-slacker). Marina coincides with Goleman (1995) and Epstein (1998) that "we are emotional intelligences. Nothing is more interesting for us than feelings, because happiness or misfortune is made of them. We act to keep a mood, to change it or to get it. They are the most close and the most alien to us". Marina defines feelings as integrated information blocks that imply a balance between:

- The actual situation that is being living;
- Desires and necessities;
- Beliefs, expectations and habits;
- The ideas about oneself.

> It is not emotions that are intelligent or not, but the automatic, preconscious thinking that underlies emotions (Epstein, 1998, p. xi in Preface).

Recent works from science education research (Otero 2006; Zembylas, 2005) question the independence of rational and emotional items, gradually considering the relationship between both domains, as will be the case in this study. In the last three handbooks on science teaching and learning there have appeared two chapters related to the affective domain (Fraser 1994; Simpson *et al.* 1994; Bell 1998; Wubbels, & Brekelman 1998; Jones & Carter 2007; Koballa & Glynn 2007).
But before presenting details on the specific topic teaching research, let's take a look on some of the components of the affective domain.

Emotions

Cognition refers to processes such as memory, attention, and language, also reasoning as problem solving and planning. Many cognitive processes are thought to involve sophisticated functions that might be uniquely human.
Besides cognition, emotions are not so easy to characterize, because they are psychological states that have unique qualities. First, unlike most psychological states emotions are embodied and consist of behavioral patterns of facial expression, comportment, and autonomic arousal. Second, they are less susceptible to our intentions than other psychological states insofar as they often trigger in direct opposition of our deliberate reason concerning them. Finally, and most importantly, emotions are less encapsulated than other psychological states as evident in their global effects on virtually all aspects of cognition (James 1890).

> Our natural way of thinking about these coarser emotions is that the mental perception of some fact excites the mental affection called the emotion, and that this latter state of mind gives rise to the bodily expression. My theory, on the contrary, is that *the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur* IS *the emotion* (James 1890, p. 743, italics and capital letters in the original).

One cannot be satisfied with such a definition that is more than a century old. Nevertheless, modern definitions are less satisfying. Some researchers incorporate the drive and motivation:

> "The definition of emotions is that emotions are states elicited by rewards and punishers, that is, by instrumental reinforcers." (Rolls 2005, p. 11)

Others favor the view that emotions are involved in the conscious (or unconscious) evaluation of events (Arnold 1960; that is, appraisals). Some approaches focus on basic emotions (Ekman 1992; for example, fear and anger), others on an extended set of emotions, including moral ones (Haidt 2003; for example, pride and envy). Strong evidence also links emotions to the body (Damasio 1994). The word «feeling» is used to characterize the mental experience of an emotion, and the word «emotion» is used to describe the organic reactions to external stimuli (Texeira dos Santos & Mortimer 2003).

In spite of this hound of definitions of «emotion» one must recognize that the learning of scientific concepts is much more than a cognitive process. Teaching is highly charged with emotions and feelings, aroused by and directed towards not just people but also values and ideals. Nevertheless, in schools and universities, for the most part, science is portrayed as a rational, analytical and non-emotive area of the curriculum, and science teachers, texts and curricular documents commonly present images of science and scientists that embody a sense of emotional aloofness (Garritz 2010).

Teixeira dos Santos and Mortimer (2003) analyze how the interaction between a high school chemistry teacher and her students from two different classes, and the emotions, affects and feelings contributed to, or obstructed, the dynamic of interactions.

In the case of mathematics, McLeod (1992) and Dogan (2012) insist that the ability to learn the subject can be significantly affected by students' concerns about the discipline. The last author presents a model of how affect factors (emotion, value, belief, attitude, etc.) and cognitive processes may interact, and that these characteristics are also commonly observed especially among pre-service teachers. America's prospective teachers show high anxiety toward and negative perception of mathematics (Hannula 2002).

In a recent work (Tomas & Ritchie, 2012) it was reviewed high school students' emotional arousal as they participated in an online writing-to-learn science project about the socio-scientific issue of biosecurity. This study revealed that pride, strength, determination, interest and alertness were among the positive emotions most strongly elicited by the students. These emotions reflected students' interest in learning about a new socio-scientific issue, and their enhanced feelings of self-efficacy in successfully writing hybridized scientific narratives in science.

Motivational beliefs

Pintrich, Marx & Boyle (1993, p. 167) presented an analysis of a conceptual change model for describing student learning by applying research on student motivation to the process of conceptual change. Since then it is recognized as the 'hot conceptual change model', in contrast with that of Posner *et al.* (1982), named by Pintrich *et al.* as the cold one. According to these authors there has been little research or theory development attempting to link motivation and cognition. In science education research, studies on conceptual change tend to ignore differences in motivational beliefs as well as classroom contextual factors that might influence the process of learning science. Pintrich *et al.* describe:

> Motivational constructs such as goal orientation, values, efficacy beliefs, and control that can serve as mediators of this process of conceptual change and are likely candidates for research on how assimilation and accommodation processes might operate in conjunction with student motivation in conceptual change instruction (1993, p. 192).

Based on developmental and educational psychology, Eccles & Wigfield (2002; pp. 110) tell us that "the Latin root of the word «motivation» means «to move»; hence, in this basic sense the study of motivation is the study of action. Motivation is commonly defined as what makes one work to obtain a reward or to avoid punishment. Emotion and motivation are closely linked as both depend on the relationship between the organism and its environment. In the case of emotion, the emphasis might be on the evaluative aspect of this relationship, whereas in the case of motivation it might be on how the organism acts in a given situation (Parkinson & Colman 1995). There has recently been published in the literature several conceptual change models related with the affective component of cognition (Cognitive Reconstruction of Knowledge Model by Dole & Sinatra 1998; Cognitive-Affective Model of Conceptual Change, by Gregoire 2003). Pintrich (2003) who did not rest until the end of his life studying motivation and Self-Regulated Learning includes a list of seven substantive questions for motivational science and in (2004) discusses the implications for research on college student motivation and its assessment for learning. Velayutham, Aldridge, & Fraser (2011, p. 2160) say that students' successful learning engagement in science is primarily determined by their level of motivation and self-regulation, and they present an instrument to measure students' motivation and self-regulation in science learning.

There are recent articles about motivational beliefs and its relationship to academic performance in college chemistry courses (Lynch & Trujillo 2011).

Interest, attitude and self-beliefs

Attitude as a construct has been defined in a myriad of ways by philosophers, psychologists, researchers and practitioners. For example, Simpson, *et al.* (1994, p. 212) define attitude as "a predisposition to respond positively or negatively to things, people, places, events, or ideas".

In their chapter of a Handbook, Jones & Carter (2007) situated attitudes as a component of an individual's belief system, having an affective domain. Beliefs, however, are integral to larger belief systems that include self-efficacy, epistemologies, attitudes and expectations. These are all interwoven and embedded in the socio-cultural context.

The PISA survey (OECD 2004; 2007) has extensively explored the competences and attitudes toward mathematics and science of students in 29 and 30 countries belonging to OECD, respectively, and the 2006 science competencies survey covered other 27 partner countries, and represent a detailed understanding of student performance in and attitudes to science.

Researchers distinguish between three different types of interest: individual, situational, and topic interest. Typically defined as ''a relatively enduring predisposition to attend to certain objects and events and to engage in certain activities'' (Ainley, Hidi & Berndorff 2002, P. 545), students' individual interest appears in a particular domain such as school subjects (science, history, mathematics), specific activities (music, sport, movies), or as a general interest in learning. It influences students' selective attention, effort, and willingness to persevere in a task, and their activation and acquisition of knowledge. In contrast, situational interest can be generated by particular conditions and/or concrete objects in the environment, for example, in the environment of the ''classroom'' by a certain text, group work, or students' active involvement in class. The third form of interest, topic interest, is trigged by a certain word, sentence, or paragraph (Nieswandt 2007).

Self-concept is a more general self-belief construct that incorporates many forms of self-knowledge and self-evaluative feelings. Historically, self-concept was defined as "a global perception of oneself and one's self-esteem reactions to that self-perception" (Marsh & Shavelson, 1985). Students' interest and attitudes toward science as well as their perceptions of how well they will perform in learning contexts (another definition of self-concept) may also play important roles in developing a meaningful understanding of scientific concepts, an understanding that goes beyond rote memorization toward the ability to explain everyday phenomena with current scientific knowledge (Nieswandt 2007).

Self-efficacy beliefs refer to students' capability to accomplish the task (Pintrich, Marx & Boyle 1993, p.185) or to "personal judgments of one's capabilities to organize and execute courses of action to attain designated goals" (Zimmerman 2000, p. 83). Value beliefs are beliefs about the importance, utility, and relevance of the task (Pintrich 2004). Self-esteem has also been defined as "two interrelated aspects: it entails a sense of a personal efficacy and a sense of personal worth. It is the integrated sum of self-confidence and self-respect. It is the conviction that one is competent to live and worthy of living" (Mruk 2006, P. 12).

Pedagogical Content Knowledge (PCK), Content Representation (CoRe) and Mortimer's Conceptual Profile Model (CPM)

Pedagogical Content Knowledge (PCK)

Shulman (1986) introduced pedagogical content knowledge (PCK) as a specific category of knowledge, one "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*" (p. 9; original emphasis). PCK essentially refers to the knowledge that teachers must have regarding how students learn specific content, the understanding of what makes the learning of a topic easy or difficult; the knowledge of the most common alternative conceptions that students may bring to the lesson, the appropriate recognition of powerful analogies, illustrations, examples, and demonstrations that may help students better understand a concept or idea, and the convenient ways to assess students' understanding (Talanquer 2004; 2005).

PCK is about the key representations that a teacher thinks to apply in the lessons about a specific topic to arrive to the outcome of appropriate learning, or in other words, is the knowledge to formulate and represent a specific topic of the discipline that make a given set of pupils understand.

As Wolfgang Klafki (1958) anticipated in his core of classes' preparation, one can summarize that PCK includes all of the representations mentioned in the following questions to the teacher (see Klafki 1995 for an English written reference):

- What basic phenomenon or fundamental principle, what law, criterion, problem, method, technique or attitude can be grasped by dealing with this content?
- What significance does the content in question or the experience, knowledge, ability or skill to be acquired through this topic already possess in the minds of the children in my class?
- What facts, phenomena, situations, experiments, controversies, etc. in other words what intuitions are appropriate to induce the child to ask questions directed at the essence and structure of the content in question?
- What pictures, hints, situations, observations, accounts, experiments, models are appropriate in helping children to answer, as independently as possible, their questions directed at the essentials of the matter?

Magnusson, Krajcik and Borko (1999) have defined PCK as consisting of five components:

(a) Orientations toward science teaching;

(b) Knowledge and beliefs of science curriculum, including national, state, and district standards and specific science curricula;

(c) Knowledge and beliefs of student understanding of specific science topics;

(d) Knowledge and beliefs of assessment in science;

(e) Knowledge and beliefs of science instructional strategies for teaching science.

Park and Oliver (2008), as a result of empirical research, considered a new affective component of PCK: «teacher efficacy», referring to "teachers' beliefs in their ability to affect student outcomes" (p. 278). Garritz (2010) has defined this sixth component as "f) Knowledge and beliefs about the affective domain related to the specific subject matter content". The following subcomponents are proposed to be considered: "motivational beliefs; goal orientation beliefs; interest and value beliefs; self-concept, self-efficacy, self-esteem, and control beliefs; all related to the teachers' interests, attitudes and emotions about their own way of teaching; the subject matter they are teaching; and their knowledge of the attitude students adopt". Furthermore, several authors had already related the affective domain with the Pedagogical Content Knowledge, as Hargreaves (1998), McCaughtry (2004; 2005) and Zembylas (2007).

Content Representation (CoRe)

Loughran *et al.* (2004) have suggested documenting and portraying PCK by two tools, one of them being the CoRe, which is a framework, developed with eight questions to be answered for each one of the central ideas on the topic. Those authors use the term «central ideas» to mean those that are at the core of understanding and teaching the topic; the ones that belong to the disciplinary knowledge normally used by the teacher to split the teaching topic. The clue is that those ideas sharply reflect the most important issues of the theme.

For each central idea, CoRe tries to find out teaching objectives; knowledge of alternative student's conceptions; troubles that commonly appear when teaching and learning; effective sequencing of topic elements and important approaches to the framing of the idea; use of appropriate analogies, demonstrations and examples; and insightful ways of testing for understanding. And in our questionnaire, also to detect strategies employed by the teacher to motivate and generate interest in students.

The authors have modified the set of eight questions of the CoRe framework of Loughran *et al.* (Table 1), including a reformulation of five of them (integrating some and ignoring others; similar to those of Padilla *et al.* 2008), and a final couple of questions related with the affective component (Park and Oliver 2008; Garritz 2010), written by the authors of this study.

Table 1. Seven CoRe questions used in this study (Questions 6 and 7 correspond to an affective component of PCK asked for each one of the central ideas mentioned in the CoRe) and three general questions (A. to C.) on the affective domain.

1. Why do you consider important for students to develop this central idea?
2. What are the difficulties or limitations of teaching this central idea?
3. What are the difficulties or limitations of students related with learning this central idea?
4. What teaching examples and procedures do you use for engaging students with this central idea?
5. What are the specific ways for ascertaining students' understanding or confusion around this central idea towards a conceptual change?
6. What is the way you use to promote students' motivation while learning this central idea?
7. What is the way you use to promote students' individual interest or topic interest for learning this central idea?

A. How do you achieve students' emotions on the topic?

B. How do you promote students' favorable attitudes towards the topic?

C. How do you help confident students's participation an expression while learning the topic?

The second tool of Loughran *et al.* (Pedagogical and Professional Experience Repertoires, PaP-eRs) has not been applied in this research yet.

Conceptual Profile Model (CPM)

Skillful teachers, it is argued, transform subject matter into forms more accessible to students, adapting it to the specific learning context, thereby developing their PCK. However, attempting to understand how PCK develops can be difficult to research because teachers do not necessarily find it easy to articulate their knowledge about what they do as practitioners. One way of gaining insight to this tacit knowledge of practice is possible through Mortimer's (1995) Conceptual Profile Model (CPM), defined as a «superindividual system of forms of thought» (p. 270), which describes different thinking and speaking routes to one concept. This means that one person could have a specific conceptual profile, depending on his/her personal philosophy, beliefs, experiences, and cultural background. According to Mortimer, this model could help researchers to deal with conceptual evolution in the classroom because it represents a change complemented by acquisition of consciousness (Mortimer 1995, p. 284). It has been applied in our case to the teaching of a specific topic, by selecting an appropriate set of conceptual profile zones.

Based on researches reported in literature (Mortimer 1995; Amaral & Mortimer 2004; Coutinho, Mortimer, & El-Hani 2007; Padilla, Ponce, Rembado & Garritz 2008; Mortimer, Scott & El-Hani 2011), we decided to use the classification of four conceptual profile zones that we further develop in the section "Condensed phase bonding teaching categories" of this paper (although we have written there an extended explanation, a short description of how to decide the classification of phrases in each of the conceptual profile zones has been included immediately, to start our analysis of what professors mentioned in their CoRes). These conceptual profile zones coincide with those already used by Padilla and Garritz (2011; Submitted 2012) and are based on the theoretical and epistemological considerations of Mortimer, Scott & El-Hani (2011):

Conceptual: Phrases related to the importance given by teachers to try students understand the fundamental concepts of bonding in condensed matter systems; to employ inductive and deductive reasoning to arrive to knowledge and to recognize that some ideas related with the different types of models for bonding generate confusion among students because they are difficult to understand.

Contextual: Sentences that use everyday problems or references that help students to contextualize experientially or historically the subject making it closer to them. It also includes learning by doing or by applying and cooperating.

Representational. Comments on the use of ways for representing the topic, such as: analogies, allegories, metaphors, demonstrations and laboratory work, stories and narratives, web-based teaching, visual schemes, controversies, *et cetera*.

Procedural: This zone is characterized by remarks on the use of algorithms and mathematical formulae as analytical tools or experimental test that conducts to a conclusion on the topic, all in an applied way but not necessarily with a complete understanding of the conceptual relationships involved.

We will refer to the conceptual knowledge to the construction of a holistic view of the content arriving to an authentic comprehension by inductive and deductive critical thinking (Arons 1997). Conceptual knowledge is assembled by using different kinds of representation forms of the concept (especially verbal, graphic and symbolic so it is much related to representational knowledge but in this case with the aim to get understood concepts). The aim is that students get a full authentic comprehension of the underlying concepts and theories; reorganize that knowledge using evidence; and to maintain a critical and more objective view of the subject. We want to point out that our definition of conceptual understanding emphasizes breadth and depth of knowledge (Alao & Guthrie 1999). Breadth is related to ‘‘the extent of knowledge that is distributed and represents the major sectors of a specific domain'' and depth to ''the knowledge of scientific principles that describes the relationship among concepts'' (p. 244).

Cloonan & Hutchinson (2011) have presented a reasoning test as an easy-to-use tool for measuring conceptual understanding and critical scientific thinking of general chemistry models and theories, by providing various types of questions that require visualization, logical reasoning, and particulate explanations. The primary goal in this work was the creation of multiple-choice questions equivalent to open-ended essay style inquiries and without rote or formula-driven responses.

Meanwhile procedural knowledge has rather an algorithmic and mathematical expression and meaning in applied actions for problem solving.

Related to the conceptual vs. procedural problem solving there is a lot of references the decade of the nineties in the *Journal of Chemical Education* (Pickering 1990; Bunce 1993; Nakhleh 1993; Zoller *et al.* 1995; Nakhleh, Lowrey, & Mitchel 1996) that were initiated by the seminal work of Nurrenbem & Pickering (1987). Those authors mention the handicap that good problem solvers have to face with conceptual problems of basic chemistry. The authors applied some problems of algorithmic nature and some that require conceptual understanding to be solved. They have found students answering problems about gases without knowing anything much about the nature of a gas, or solving limiting-reagent problems without understanding the nature of chemical change. The literature contains evidence that novice problem solvers in chemistry usually have greater success by solving problems of an algorithmic mode than problems having a more conceptual base (Bunce 1993; Nakhleh 1993). Niaz & Robinson (1992) concluded that student training in algorithmic-mode problems did not guarantee successful understanding of conceptual problems: "algorithmic and conceptual problems may require different cognitive abilities." (p. 54).

It has been stressed by Nieswandt (2007) that conceptual understanding of science is a complex phenomenon. It incorporates an understanding of single concepts such as «mass» or of more complex concepts such as «bonding» —declarative or factual knowledge— which, following certain rules and models, combines multiple individual concepts —e.g., particle model, mass conservation, amount of substance, equivalent, covalent, ionic, *et cetera* — results in a new concept. Thus, conceptual understanding comprises «declarative knowledge», «procedural knowledge» —concepts, rules, algorithms— and «conditional knowledge» —the understanding of when to employ procedural knowledge and why it is important to do so.

Recently Salta & Tzougraki (2011) investigated more than one thousand students' (of grades 9th and 11th) performance with problems of conservation of matter during chemical reactions. These authors classified the problems in three types: «algorithmic-type», «particulate-type», and «conceptual-type». All the students had a far better performance in particulate-type problems than in the other two. Although students' ability in solving algorithmic-type problems increases as their school experience in chemistry progresses, their ability in solving conceptual-type problems decreases. Holme & Murphy (2011) have design two exams in which 3000 students had roughly equivalent performances on conceptual and algorithmic items.

The subject matter concepts involved in this study.

The correct understanding of the concept of bonding in General Chemistry courses is of capital importance (Pauling 1960) and the bond present on multidirectional networks is a difficult topic for students (Gillespie & Popelier 2001), so the PCK's documentation of renowned teachers can be very useful for the professional training of pre-service teachers (Reyes & Garritz, 2006; Hume & Berry, 2011). There have been several recent publications on ICTs and teaching/learning sequences boarding the topic of chemical bonding (García Franco & Garritz, 2006; Levy Nahum, Mamlok-Naaman, Hofstein, & Krajcik 2007; Frailich, Kesner & Hofstein 2009; Hilton & Nichols 2011).

The disciplinary contents analyzed in this study are the bonding models of solid or liquid phase substances at College level. The problem is the documentation of the way General Chemistry professors deal with when teaching this topic. We will refer to them as 'teachers' instead of 'professors' in what follows.

In General Chemistry course the teacher faces a problem when introducing bonding in solid or liquid substances, because there are several bonding models applicable:

1) The Covalent molecular bonding; with covalent bonding at the intramolecular level, but with intermolecular interaction strong enough to constitute a condensed phase substance. Sugar is an example.
2) The Ionic bonding; Positive and negative ions in a crystalline network. Sodium chloride is an example.
3) The Metallic bonding; Metal ions surrounded by free valence electrons. Lithium and Gold are examples.
4) The Multidirectional covalent bonding; of atoms linked with covalent bonds forming a network. Diamond is an example.

These bonding models are included, for example, in chapter 9 (Solids) of Spencer, Bodner & Rickard (2006), with the heading of a triangular scheme of the van Arkel type (1949, see also Jensen, 1995; Sproul 2001), which is used to classify molecular, ionic, metallic and network covalent solids (figure 1).

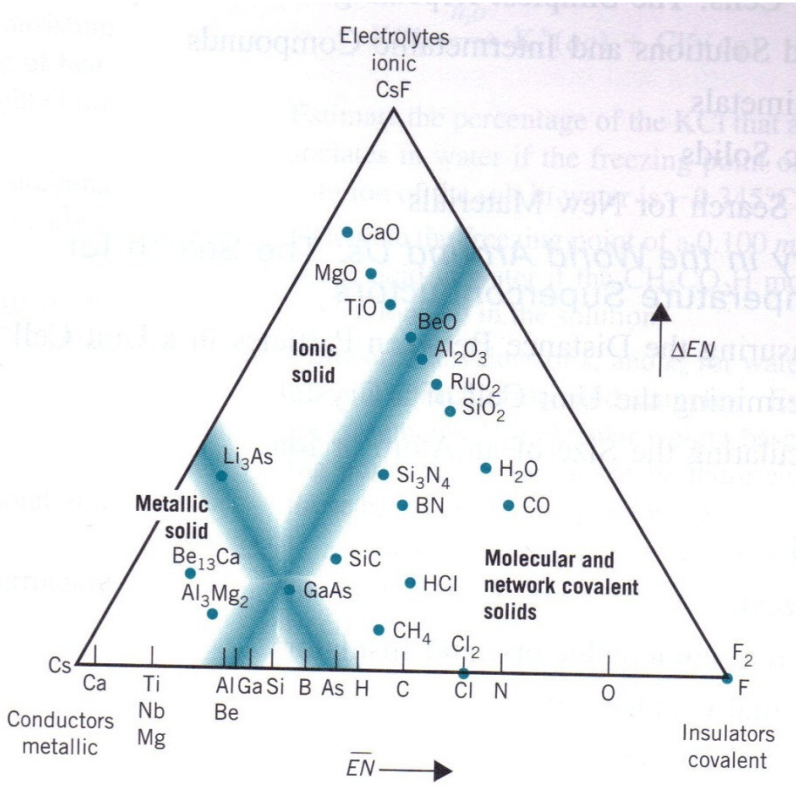
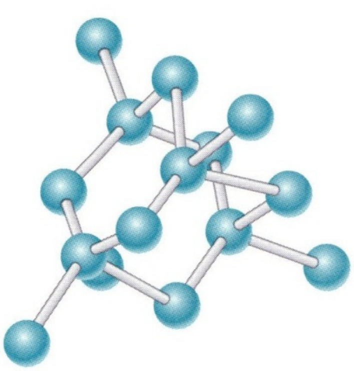
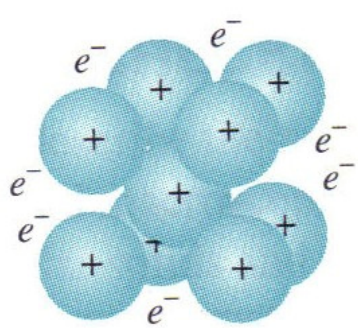


Figure 1. Bond-type triangle for selected compounds, with an arbitrary division established to separate and classify solids as molecular, network covalent, ionic and metallic. The axes are the differences in electronegativity (ordinates) and the average electronegativity (abscissas) of the pair of elements that constitute the compound. (Taken from Spencer *et al.*, p. 360).

a) 

b) 

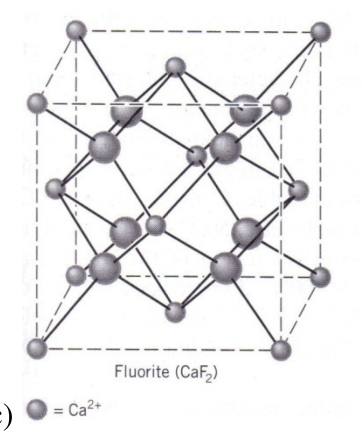
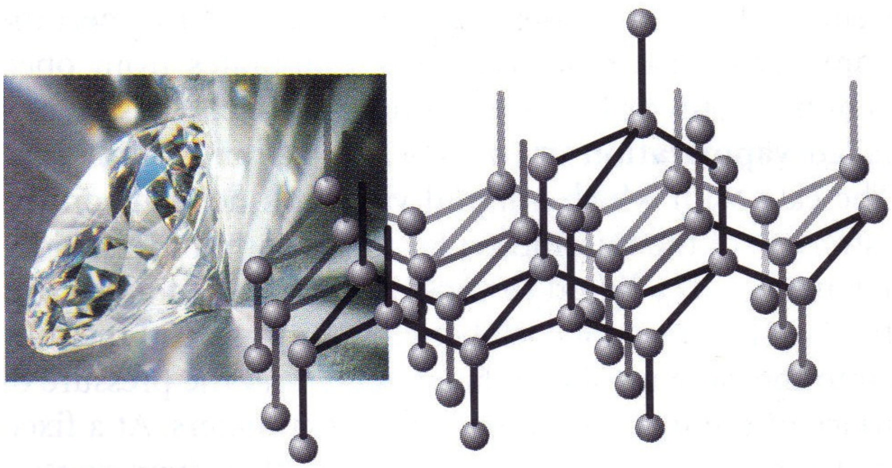
c) 

Figure 2. a) Diamond simplest repeating unit. Each carbon is bound to other four neighboring carbon atoms arranged toward the corners of a tetrahedron. b) The force of attraction between the positive charged metal ions and the surrounding sea of electrons in a metal is called a metallic bond. c) Example of an ionic compound, fluorite, with the smallest ions being Ca^{2+} (in a face centered cubic unit cell) and the largest the eight fluorine, F^- (inside the unit cell) (Taken from Spencer *et al.*, pp. 363,366 and 377).

Spencer *et al*. proceed to establish the relationship between the physical properties and the type of model that characterizes the solid. For example, in covalent type solids they present the different properties of the allotropes of carbon: diamond, graphite and buckmisterfullerenes.

Several diagrams are used by all books (for example, three of them by Spencer *et al*. are included in Figure 2) to represent the spatial distribution of atoms and ions in the networks. Gillespie and Popelier (2001) also include a chapter discussing the type of bond and the physical properties inherited by the compound.

Diamond and graphite images are also used by Atkins & Jones, (2010) to represent network solids (see figure 3). The student participants in Hilton & Nichols (2011) study increased in representational competence and conceptual understanding of chemical bonding through writing and thinking in representations as those shown in these figures.



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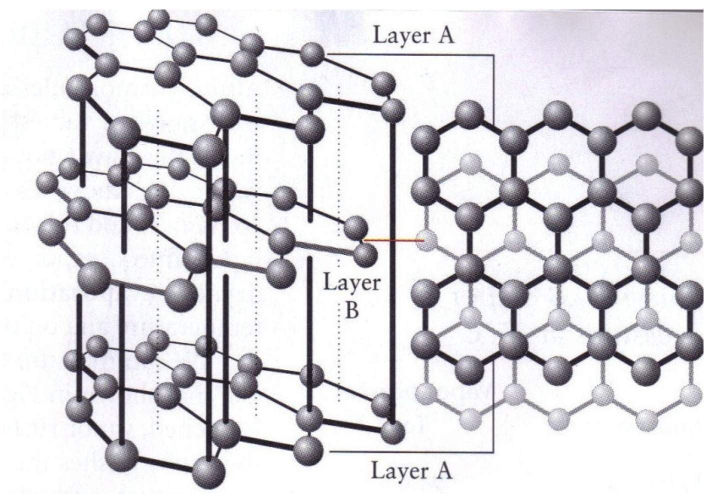

b)

Figure 3. a) Part of the structure of a diamond. Each sphere represents the center of a carbon atom, which is bonded by four hybrid covalent links to its four neighbors. The highly regular structure results in the smooth crystal faces seen in the photograph. b) Graphite consists of staggered layers of hexagonal rings of carbon atoms. On the left a view along the layers; on the right, a view perpendicular to them. The slipperiness of graphite is due to the ease with which the layers can slide over one another. (Taken from Atkins & Jones, p. 453)

Methodology

Description of the four teachers

We start by selecting four professors by the characteristic of being recognized by their peers as outstanding ones. All of them got their PhD at the University where they work and a Posdoctorate at some international recognized university. Three of them are full time professors of the Department of Inorganic Chemistry in the same University, and one is a part time professor. All of them regularly publish papers about diverse Inorganic Chemistry topics.
In the initial interviews it was explored their opinion on the central ideas to be considered in the CoRe questionnaire and also their initial expression about the first five CoRe questions (see Table 1).

As some of them mentioned 'attitudes', 'motivation', and 'emotion' as important factors to deal with when teaching (by filling a first CoRe questionnaire with five questions), we considered making a second interview including the three general questions (A to C) of Table 1 related with the affective domain of teaching and complementing the questionnaire with questions 6 and 7.
This first questionnaire was filled by each one of the teachers including a set of central ideas, which were different for all of them. In order to elaborate a set of consensual central ideas and to have a comparable set of answers in the four CoRe questionnaires, the second interview was useful to the authors to make a proposal of central ideas, trying to get together those mentioned by each one of the teachers in the first delivery. That new set was considered and debated by the four teachers, and a consensus was attained, arriving to those central ideas listed in Table 2.

Table 2. Set of central ideas arrived through consensus with the four General Chemistry teachers:
a) Physical properties;
b) Bonding parameters (dissociation energy and distance);
c) Polarity and intermolecular interaction in molecular bonding;
d) Networks (metallic, ionic and covalent).

The set of seven questions of Table 1 CoRe was asked to the four General Chemistry teachers for each one of the central ideas shown in Table 2, constructing a matrix with the central ideas in the first line and the questions in the first column. All of these questions involved the affective domain like *emotion*, *positive attitudes* and *confident participation and expression* and those in CoRe about *motivation* and *interest* were answered with fluency, clarity and spontaneity by the teachers. It was necessary to give the teachers the definition of the affective constructs, what was done by writing them at the end of the CoRe questionnaire, with an asterisk in the point where they appeared on each question, before they begin to answer their questionnaires the second application. The authors gave the four teachers a period of about one month for answering the final CoRe framework.

Condensed phase bonding teaching categories

The phrases given by each teacher were then classified using the conceptual profile model of Mortimer (1995). A first explanation on the selected Conceptual Profile Zones (CPZ) has been already given in the section "Conceptual Profile Model (CPM)" of this study, but now we want to extend a little the meaning of each one of them. The authors decided to select the following four CPZs:

Conceptual: conceptual knowledge implies the construction of a holistic view of the content to get a full authentic comprehension of underlying concepts and theories; to reorganize that knowledge using evidence; and to maintain a critical and more objective view of the subject. Conceptual understanding is also interpreted as students' ability to apply the learned scientific concepts to scientific phenomena in everyday life situations. Some examples of sentences with these characteristics are "Although pupils have a notion about the concept, most of them cannot define 'chemical bond'. The reason is that all definitions seems to be ambiguous because we speak of chemical bonding when species with certain stability are formed as independent entities, but what does 'certain' mean?" or this other one "One of the purposes of explaining bonding models and molecular interactions is that those concepts allow to explain physical properties of substances" (These two examples of conceptual kind texts were written by teacher 2).

Contextual: These kinds of notions are constructed by individuals according with the social and historical context they experience; the contextualizations of concepts which are very abstract or historical narratives are important tools for teaching.
Concepts or processes such as "organoleptic properties" or "physical and chemical changes as every day phenomena" or questions as "Why ionic bonding breaks easily when dissolving an ionic substance in water, while a covalent substance does not dissolve?" or phrases like those two "the historical narratives on the mechanical equivalent of heat" and "commenting and explaining Nobel Prizes of years 2000 and 2010, related to conducting polymers by Heeger, MacDiarmid and Shirakawa or to graphene, by Novoselov and Geim" are of the contextual type (These two examples of contextual type texts were written by teacher 3). The Contextual profile zone also involves ideas with an ethical sense without a formal scientific approach. Here belong practical ideas that are mentioned without a clear relation between phenomenon and theory.

Representational: One of the most interesting strategies that are reported in literature is the one related with different kinds of representations to improve learning. We have found the following ones: analogical, visual, analogue maps, lab experiments or demonstrations, molecular models, and material models. In chemistry, the understanding of complex concepts on multiple levels is not achievable without an understanding and ability to use and integrate multiple representations within nanoscopic and symbolic levels (Ardac & Akaygun, 2004; Wu & Shah, 2004). Some examples of phrases within this Representational CPZ also written by teacher 3 are the following: "I use molecular diagrams, photographs, X-Ray schemes to represent the chemical structure of substances" or "I employ analogies with magnets and ask students to imagine what happens in a tray with those rectangular magnets in movement".

Procedural: Procedural knowledge is one that requires the use of a memorized set of procedures for the solution of a problem, which denotes dynamic and successful utilization of particular rules, devices, experiments, demonstrations or algorithms within relevant representation forms. "If we take about 250 mL acetone and start pushing inside polystyrene glasses, it is impressing how many of them can be dissolved", is an example of sentence of the procedural type, written by teacher 2 to teach that «similar dissolves similar».

Each one of the matrix elements of the teachers' CoRes were carefully read line-by-line by the two authors in order to analyze its content and classify it partially or totally inside a given CPZ. Where some incongruences on the two classifications appeared, the two authors decided to ask a third person and finally put the phrase in one of the two CPZs or in both of them if the arguments are equilibrated. In the "Findings and Analysis" section of this article results are presented with the count and percentages of times each one of the teachers uses each of the four CPZs declared for this study.

Findings and Analysis

We shall make the analysis by writing some verbatim sentences directly related to the content or to the affective domain of teaching and learning and giving our appreciation on them.

Sentences related to the content of condensed matter bonding models

One has to prove students that «polarity» does not imply the presence of ionic charges, by analyzing that polar molecules' substances (as water, ethyl alcohol, acetone, sugars in solution) do not conduct electricity. Teacher 3.

This is a usual misconception of students, because polar substances are represented with partial charges δ^+ and δ^- in some of their atoms, that are not integer numbers, so that polarity do not imply ionicity.

A throughout analysis of the metallic networks of sodium and iron is needed, emphasizing their electric conduction capacity in solid state and that their melting points and enthalpies are not always very high (as is the case for mercury). The unique thing that fully characterizes metals is that they conduct electricity in their elemental state. Teacher 3.

It is very important to convince students that the metallic network is not a directional set of bonds (as it is the case in covalent or ionic solids) but a widespread attraction of metallic ions to free electrons. The last are responsible for the electricity conduction of metals, a different mechanism present in the melted ionic salts.

> It is a great number of students those who look for information at the Internet when some topic is leave to search for as homework for the next class. When one writes "chemical bond" in Google it appears more than one million pages. They go opening pages, selecting some, and finally giving “cut & paste” of some of the information. This way of working is thoroughly reprehensible because students usually do not retain any of the written homework. Nothing is better than to read the corresponding topics in a textbook. Teacher 2.
>
> We have to support the model abstraction with visualization made via interactive software on the computer. The typical examples are the 3D comparison of different network structures with the computer, that help students grasping a mental image of the interactions, bonding distances and energies, *et cetera.* Teacher 4.
>
> On bond distance and energy, we analyze those concepts with some multimedia programs, for example with *Hyperchem* or archives constructed with *Mercury*, where students are able to measure the distance between atoms with the cursor, arriving to the conclusion of having covalent bonding or not. Teacher 2.

This three sentences show how information and communication technologies can be useful to represent complex chemistry diagrams and use interactive software to arrive to certain conclusions of complex bonding phenomena, but might be condemned for its unintelligent use.

> I always start the topic of chemical bonding with a question: How do we know experimentally that two chemical species (either individual atoms or more complex units) are bonded? What criteria can we employ? Teacher 1.
>
> Metallic bonding is presented comparing physical and chemical properties of metals, with the use of multimedia models explaining why metals are malleable, for example. Teacher 4.
>
> When the topic on physical properties of substances is boarded I use to show the thin and illusory border that exists between physics and chemistry, by means of examples of the usual conclusive differences between both kinds of phenomena. For example, students are somewhat convinced that a physical phenomenon occurs when salt is dissolved in water, but it is easy to call it into question by analyzing with them the existent complexity of the approximation of water molecules to ions, positive or negative, its solvation and separation from the ionic lattice. Without doubt a radical restructuration of matter. A second example is the supposedly chemical reaction from diamond to graphite (with no change of composition), that in spite of the great bonding transformation from one species to the other it does not reflect a high enthalpy. Nevertheless, the boiling of water, although it has a higher enthalpy change it is considered by students as a physical change. Teacher 1.

The basic concepts of the General Chemistry course are remembered by teachers, as can be seen in these three phrases. This epistemological order of the topics is of fundamental importance for the students to construct meaningful learning.

Sentences related to the affective domain

About the answers of three general questions (A., B. and C. of Table 1) of the affective dimension the authors found, for example, the following answers:

> The main emotion I pretend to awake in students is confusion, because then anxiety also arouses to solve their contradictions and paradoxes. For example: How clothes can be dried at room temperature if the water is not boiling? Shaking their certainties transforms students' attitudes in a participative way. This kind of «contradictions» or «paradoxes» can produce confusion but at the same time awake a sensation of *anxiety to solve the problem*. Shaking their certainties can transform students' attitudes in a participative way. Teacher 1.
>
> It is possible to awake positive emotions related with joy or astonishment with examples related to every day substances, like water. To provoke positive attitudes I underline aspects that shown the utility of the theme in relation with our conception of materials and substance around us. Teacher 2.
>
> I put a special emphasis in showing an affective reply, considering that "mistakes are logically comprehensible". In a group discussion I detect and make clear an update, incomplete or false information (for example: "*all ionic compounds are soluble on water*"), to awake in students the *curiosity or interest* to change their incorrect concepts. Teacher 3.
>
> I promote the participation of students in different ways, ludic for example. I give "cultural briefs" or curious information to catch the attention of students. To make "coarse" comparisons with daily life became a good strategy. For example: When I speak of polarization I compare the species of little polarizability with flat belly people and those of high polarizability with obese ones. Teacher 4.

The authors would like to emphasize that some of the analogies used to motivate and create interest in students are absolutely related to the content, that is, they are ways of impact on the affective domain that are related to the specific academic topic. That is why the authors insist that this knowledge forms part of pedagogical content knowledge, and it is of different kind of the five components mentioned by Magnusson et al. (1999).

Lynch, & Trujillo (2011) analyze the source of motivation with students entering college chemistry courses. Those authors have found that academic performance (self-efficacy) is closely related to student motivational beliefs and learning strategies.

For our teachers, the sources of motivation are slightly different:

> I try to motivate my students by creating doubts on them and giving a different vision of the world around us by means of different resources. For example, the intrinsic motivations are the type more used by me, because I give them software, documents and material to install and visualize the results of solid and molecular structures. In second place I use the relevance to learn chemistry to understand the world around us. In third place I use self-efficacy, because thanks to discussions and analysis of the topics they realize on their own capacity to develop a task. Teacher 2.
>
> I give examples relating the last technologies (as transistors and semiconductors) and the network model. Furthermore, making him to realize that in every day behavior they live with several covalent networks, as jewels or glasses. Teacher 3.

About the central ideas displayed in Table 2: the «network» concept plays a useful description to give account of the last three bonding models mentioned in the beginning of section 'The subject matter concepts involved in this study'. The four teachers interviewed present this concept to their groups, trying to achieve the students' conceptual comprehension of it, as a multidirectional type of bonding.

Conceptual profile model used to characterize answers of the teachers

The result of classifying each one of the sentences written in their CoRes as partially or totally belonging to a given CPZ is shown in figure 4. That task could be done with an average of twenty eight sentences for each teacher (29 for teacher 1; 22 for 2; 31 for 3 and 35 for 4).
It can be seen that all teachers' phrases fall between 24 to 39 percent in the first CPZ, the Conceptual one; but there are serious differences in the other three zones, with teachers 1, 3 and 4 being mainly Representational (between 27 and 30%); Teachers 3 and 4 being highly contextual (once again more than 30%) and teacher 2 chiefly Procedural (24 %).

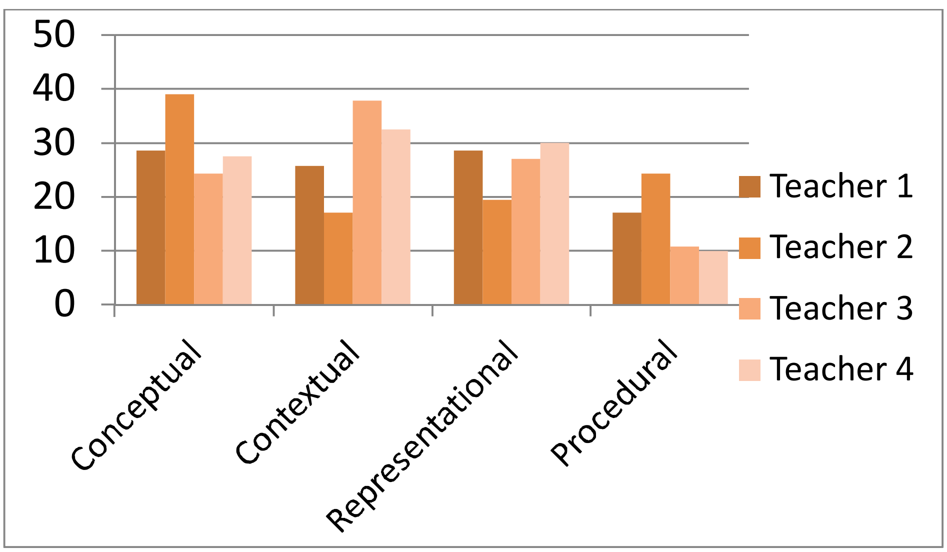

Figure 4. Percentage of sentences in each teachers' CoRe categorized by each of the four conceptual profile zones described in the methodology section.

Examples of affective sentences in several conceptual profile zones

In the CoRe answers and its classification in the CPZs, several affective sentences related with the topic were also found, which could be characterized as part of teachers' PCK. A thing important to underline is that these affective answers not only belong to the last two questions in the CoRe but the answers to some other questions also display emotional characteristics. Some examples are the following:

Representational:

> I mention that human beings tend to classify (and simplify) Nature in order to understanding it better, but we usually end with a classification only in two boxes: one with the label 'white' and the other 'black', being that Nature has a wide zone of gray shades. Teacher 1.
>
> In the topic of intermolecular interactions at some moment I usually refer to solubility and remember students that 'similar dissolves similar'. So it is very useful at that point to set an activity to compare the chemical structure of nails' varnish with the polystyrene foam of hot water glasses. Teacher 2.

These two phrases reveal ways to represent knowledge, as a simple comparison of extreme black and white boxes or a procedure for giving emphasis on some chemical comparison principles.

Teacher 4 uses a representational set of analogies to teach and motivate students to the topic, such as the following two:

> A molecular solid network is like a ballroom where there are many couples dancing, each couple represents a molecule and each person an atom. Inside one couple the union is tight and the distance is short, but between couples the interaction is weak and the distance between them is outstandingly larger.
>
> Bond distances and bond energies can be correlated with several non-chemical similes, for example a starting couple of a boyfriend and a girlfriend, when all is love and happiness and their attraction is high (high bonding energy) this implies the short bonding distance between both.

Procedural:

> Processes such as 'construct and take the models of NaCl and CaF_2 to the classroom' or 'give values of electronegativity, distances and geometries to interpret the physical state of the substances —as H_2O and H_2S'. Teacher 1.
>
> How similar is the nail polish remover to a polystyrene glass in which we have a hot coffee? This is useful because a high number of glasses can be dissolved in 250 mL of acetone, which implies that a substance is dissolved by a similar solvent. Teacher 2 talking about the solubility of similar substances and solvents.

> I challenge the group to design an experimental procedure to determine if there are certain molecules or not in a test substance. Teacher 3.

The procedural profile zone is characterized by the use of algorithms and mathematical formulae or experimental tests, so it is a challenging way of motivating students to convince them of some theoretical or nanoscopic non-common-sense knowledge.

Contextual:

> I try to present some of the consequences of intermolecular forces while taking about soaps and detergents (cleanliness in general), but also about the cell membrane and the transport of substances through it, or to mention the most sophisticated technologies, as the LCD screens. The idea behind those elements is that the students realize the validity and applicability of knowledge and how it can transform our lives. Once again the motivation that is pursued is an intrinsic motivation and also associated to self-efficacy. Teacher 1.

> When I introduce "soft interactions" I enjoy with the example of ice, because its structure is maintained via hydrogen bridge interactions (something very accepted by students). Then I show photos of an iced hotel as the Norway's Kirkenes Snow Motel, and the television series "Ice Road Truckers", in which trailers with 60 tons go over the iced surface of the Great Lake at 25 km/hr. From the analysis of these soft interactions appears a hard material, as the ice. Teacher 2.

> Emotions can be liberated informing the students about scientific, technological and social importance of network substances, as diamond, carborundum, metals, common salt, etc. Teacher 3.

> We enter to games and interviews about the topic and some questions as the following arise: If we want to give something special to a person, why we offer gold jewelry as a gift? What other metal could be used? Why don't we give NaCl rings, in spite that this substance also forms beautiful periodic networks? Teacher 4.

We see that we have classified as contextual sentences that mention everyday items to help students contextualizing experientially or historically the subject. It also can be seen that it includes learning by doing or by applying and cooperating.

Conclusion

Historically, emotion and cognition have been viewed as separate entities. One factor that could have contributed for this separation in the past century is methodological. But now in many cases, we must go beyond understanding interactions, some of which are suggested to be mutually antagonistic. As stated by Gray and colleagues (2002, p. 4115), "This highly specific result indicates that emotion and higher cognition can be truly integrated, i.e., at some point of processing, functional specialization is lost, and emotion and cognition conjointly and equally contribute to the control of thought and behavior". This statement summarizes the findings that although emotion and cognition are partly separable, often true integration of them takes place, strongly blurring the distinction between the two.

This study reveals that emotions are intertwined with specific knowledge construction in the relations among students and teachers and that it suggests that beliefs, attitudes and emotions should be from now important factors to contemplate in Science Education, because cognition and emotion are not considered separate items in human activity. A good teacher must have a wide variety of affective domain responses specific for science teaching to face, for example, beliefs about science, beliefs about its teaching, attitudes toward science and emotions (as frustration and anxiety on problem solving).

On the topic of condensed phase substances' bonding models, the four interviewed professors defined consensually the following as central ideas: Physical properties; Bonding parameters (dissociation energy and distance); Polarity and intermolecular interaction in molecular bonding; and Networks (metallic, ionic and covalent), this last one being a recent and very useful to explain ionic, metallic and covalent-solid models.

The answers and well disposition of the professors towards the three general questions involved with the affective domain and related to *emotions*, *positive attitudes* and *confident participation and expression by students* and also with those on *motivation* and *individual or topic interest* added to Loughran's et al CoRe were answered with spontaneity by them. Even more, after having given the definitions of the emotional concepts the authors detected enthusiasm in the professors because they properly used those definitions in their own texts written.

It was clear in the proportion of phrases answered within each one of four conceptual profile zones that each one of the four interviewed professors has their own way to teach the topic. No matter the emphasis on the conceptual zone, present in all of them, the contextual, representational and procedural ones show substantial differences in the professors' PCK.

References

Ainley, M., Hidi, S. & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal or Educational Psychology*, 94, 545-561.

Alao, S., & Guthrie, J.T. (1999). Predicting conceptual understanding with cognitive and motivational variables. *The Journal of Educational Research*, 92, 243-254.

Amaral, E.M.R. & Mortimer, E.F. (2004) Un perfil conceptual para entropía y espontaneidad: una caracterización de las formas de pensar y hablar en el aula de Química [A conceptual profile for entropy and spontaneity: a characterization on ways of thinking and speaking in the chemistry classroom], *Educación Química,* 15(3), 218-233.

Ardac D. & Akaygun, S. (2004). Effectiveness of multimedia-based instruction that emphasises molecular representations on students' understanding of chemical change. *Journal of Research in Science Teaching*, 41(4), 317-337.

Arons, A. B. (1997). *Teaching Introductory Physics*, Chapter 13: «Critical thinking», USA: Wiley.

Arnold, M. B. (1960). *Emotion and personality,* New York: Columbia University Press.

Atkins, P. & Jones, L. (2010). *Chemical Principles. The quest for insight*, 5th edition. USA: W. H. Freeman.

Bell, B. (1998). Teacher development in science education. In Fraser, B. J. & Tobin, K. (Eds.). *International Handbook of Science Education* (Chapter 6.3; pp. 681-694). Dordrecht: Kluwer.

Bunce, D. M. (1993). Introduction: Symposium: Lecture and learning: Are they compatible? *Journal of Chemical Education,* 70(3), 179–180.

Cloonan, C. A. & Hutchinson, J. S. (2011). A Chemistry Concept Reasoning Test, *Chemistry Education Research and Practice*, 12, 205–209.

Coutinho, F. A., Mortimer, E. F. & El-Hani, C. N. (2007). Construção de um perfil para o conceito biológico de vida [Building of a conceptual profile of "life"]. *Investigações em Ensino de Ciências* 12(1), 115-137.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Avon Books.

Davidson, R. J., Scherer, K. R. & Goldsmith, H. H, (2003). Introduction: Neuroscience, in Richard J. Davidson, Klaus, R. Scherer, & H. Hill Goldsmith (Eds), *Handbook of the affective sciences.* (p. 3-7). Oxford: Oxford University Press.

Dogan, H. (2012). Emotion, Confidence, Perception and Expectation. Case of Mathematics, *International Journal of Science and Mathematics Education*, 10, 49-69.

Dolan, R. J. (2002). Emotion, Cognition, and Behavior, *Science,* 298, 1191-1194.

Dole, J. A. & Sinatra, G. M. (1998). Reconceptualizing Change in the Cognitive Construction of Knowledge, *Educational Psychologist*, 33(2-3), 109-128.

Eccles, J. S. & Wigfield, A. (2002). Motivational Beliefs, Values, and Goals, *Annual Review of Psychology*, 53, 109-32.

Ekman, P. (1992). An argument for basic emotions. *Cognition & Emotion,* 6, 169-200.

Epstein, S. (1998). *Constructive Thinking: The Key to Emotional Intelligence*, Wesport, CT, USA: Praeger Paperback.

Frailich, M., Kesner, M. & Hofstein, A (2009). Enhancing Students' Understanding of the Concept of Chemical Bonding by Using Activities Provided on an Interactive Website, *Journal of Research in Science Teaching*, 46(3), 289-310.

Fraser, B. J. (1994). Research on classroom and school climate. In D. Gabel (Ed.) *Handbook of Research in Science Teaching and Learning*. (Chapter 17; Pp. 493-541). New York: Macmillan.

García Franco, A. & Garritz, A. (2006). Desarrollo de una unidad didáctica: el estudio del enlace químico en el bachillerato, [Development of a Didactic Unit; Chemical bonding study in High School], *Enseñanza de las Ciencias,* 24(1), 111-124.

Garritz, A. (2010). Pedagogical Content Knowledge and the affective domain of Scholarship of Teaching and Learning, *International Journal for the Scholarship of Teaching and Learning*, 4(2), 1-6. It can be retrieved from the URL (last retrieval on February 16th, 2012), http://academics.georgiasouthern.edu/ijsotl/v4n2/personal_reflections/_Garritz/index.html

Gillespie, R. J. & Popelier, P. L. A. (2001). *Chemical Bonding and Molecular Geometry: From Lewis to Electron Densities*, New York, NY, USA: Oxford University Press, 268 pp. ISBN 0-19-510496-X.

Goleman, D. (1995). *Emotional Intelligence*, New York: Bantam Books.

Gregoire, M. (2003). Is It a Challenge or a Threat? A Dual-Process Model of Teachers' Cognition and Appraisal Processes during Conceptual Change, *Educational Psychology Review*, 15(2), 147-179.

Goswami, U. (2006). Neuroscience and education: from research to practice? *Nature Reviews Neuroscience*, 7, 406-413.

Gray, J. R., Braver, T. S. & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, 99, 4115–4120.

Haidt, J. (2003). The moral emotions, in Richard J. Davidson, Klaus, R. Scherer, & H. Hill Goldsmith (Eds), *Handbook of the affective sciences.* (p. 852-870). Oxford: Oxford University Press.

Hannula, S. M. (2002). Attitude towards mathematics: Emotions, expectations and values. *Educational Studies in Mathematics*, 49, 25–46.

Hargreaves, A. (1998). The emotional practice of teaching. *Teaching and Teacher Education,* 14(8), 835-854.

Hilton, A. & Nichols, K. (2011). Representational Classroom Practices that Contribute to Students' Conceptual and Representational Understanding of Chemical Bonding. *International Journal of Science Education*; 33(16), 2215-2246.

Holme, T. & Murphy, K. (2011).Assessing Conceptual and Algorithmic Knowledge in General Chemistry with ACS Exams, *Journal of Chemical Education,* 88(9): 1217-1222.

Honey, P. & Mumford, A. (1982). *The Manual of Learning Styles*. Maidenhead, UK: Peter Honey Publications.

Hume, A. & Berry, A. (2011). Constructing CoRes —a Strategy for Building PCK in Pre-service Science Teacher Education, *Research in Science Education*, 41,341–355.

James, W. (1890). *The Principles of Psychology*, New York, Holt.

Jensen, W.B. (1995). A quantitative van Arkel diagram. *Journal of Chemical Education,* 72(5), 395-398.

Jones, M. G. & Carter, G. (2007). Science Teacher Attitudes and Beliefs. In Abell, S. K. & Lederman, N. G. (Eds.), *Handbook of Research on Science Education* (Chapter 35; pp. 1067-1104). Mahwah, N.J.: Lawrence Erlbaum.

Klafki, W. (1958). *Didaktische Analyse als Kern der Unterrichtsvorbereitung*, Basel: Wienheim.

Klafki, W. (1995). On the problem of teaching and learning content from the standpoint of critical-constructive didaktik. In S. Hopmann and K. Riquarts (eds) *Didaktik and/or Curriculum*, (pp. 187-200), Kiel, Germany: Institute fur die Pädagogik der Naturwissenschaften (IPN).

Koballa, T.R. Jr. & Glynn, S.M. (2007). Attitudinal and Motivational constructs in science learning. In Abell, S. K. & Lederman, N. G. (Eds.) *Handbook of Research on Science Education*, (Chapter 4, Pp. 75-102), Mahwah, NJ, USA: Erlbaum.

LeDoux, J. E. (1996). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.

Levy Nahum, T., Mamlok-Naaman, R., Hofstein, A., & Krajcik, J. S. (2007). Developing a new teaching approach for the chemical bonding concept aligned with current scientific and pedagogical knowledge. *Science Education,* 91(4), 579–603.

Liljedahl, P. G. (2005). Mathematical discovery and *affect:* the *effect* of AHA! experiences on undergraduate mathematics students. *International Journal of Mathematical Education in Science and Technology,* 36(2-3), 219-235.

Loughran, J. J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing Ways of Articulating and Documenting Professional Practice. *Journal of Research in Science Teaching*, 41(4), 370–391.

Lynch, D. J. & Trujillo, H. (2011), Motivational Beliefs and Learning Strategies in Organic Chemistry, *International Journal of Science and Mathematics Education*, 9(6), 1351-1365.

Magnusson, S., Krajcik, J., & Borko, H. (1999).Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, Lederman, N. (Ed.), *Examining pedagogical content knowledge* (pp. 95-732). Dordrecht, The Netherlands: Kluwer Academic Press.

Marina, J. A. (1998). El laberinto sentimental [The sentimental labyrinth], Madrid: Anagrama.

Marsh, H. W. & Shavelson, R. (1985). Self-concept: Its multifaceted, hierarchical structure. *Educational Psychologist,* 20**,** 107–123.

McCaughtry, N. (2004). The emotional dimensions of a teacher's pedagogical content knowledge: Influences on content, curriculum, and pedagogy. *Journal of Teaching in Physical Education*, 23, 30–48.

McCaughtry, N. (2005). Elaborating pedagogical content knowledge: what it means to know students and think about teaching. *Teachers and Teaching: theory and practice,* 11(4), 379–395.

McLeod, D. B. (1992). Research on affect in mathematics education: A reconceptualization. (In D. A. Grouws (Ed.), *Handbook of Research on Mathematics Teaching and Learning* (pp.575-595). New York: Macmillan).

Mortimer, E. F. (1995). Conceptual Change or Conceptual Profile Change? *Science & Education*, 4, 267-285.

Mortimer, E. F., Scott, P. & El-Hani, C. N. (2011). Bases teóricas e epistemológicas da abordagem dos perfis conceituais [Theoretical and epistemological grounds to deal with conceptual profiles], *Tecné, Episteme & Didaxis*, vol. Extraord. (5th International Conference, October, Bogotá, Colombia), 77-90.

Mruk, C. J. (2006). Defining self-esteem: an often overlooked issue with crucial implications. (In M. H. Kernis (Ed.), *Self-Esteem Issues and Answers. A Sourcebook of Current Perspectives,* New York: Psychology Press).

Nakhleh, M. B. (1993). Are Our Students Conceptual Thinkers or Algorithmic Problem Solvers? Identifying Conceptual Students in General Chemistry, *Journal of Chemical Education*, 70(1), 52-5.

Nakhleh, M. B., Lowrey, K. A. & Mitchel, R. C. (1996). Narrowing the Gap between Concepts and Algorithms in Freshman Chemistry, *Journal of Chemical Education*, 73(8), 758-762.

Niaz, M., & Robinson, W.R. (1992). From 'algorithmic mode' to 'conceptual Gestalt' in understanding the behavior of gases: An epistemological perspective. *Research in Science & Technological Education,* 10, 53–64.

Nieswandt, M. (2007). Student Affect and Conceptual Understanding in Learning Chemistry. *Journal of Research in Science Teaching*, 44(7), 908-937.

Nurrenbem, S. C. & Pickering, M. (1987). Concept Learning versus Problem Solving: Is there a difference? *Journal of Chemical Education*, 64(6), 508-510.

OECD (2004). *Learning for Tomorrow's World – First Results from PISA 2003*, Paris: OECD.

OECD (2007). *PISA 2006. Science competencies for tomorrow's world*. Paris: OECD.

Otero, M. R. (2006). Emociones, Sentimientos y Razonamientos en Didáctica de las Ciencias [Emotions, feelings and reasoning in Science Education]. *Revista Electrónica de Investigación en Educación en Ciencias*, 1(1). Retrieved February 16, 2012, from http://reiec.sites.exa.unicen.edu.ar/ano-1-nro-1.

Padilla, K., Ponce-de-León, A. M., Rembado, F. M. & Garritz, A. (2008). Undergraduate Professors' Pedagogical Content Knowledge: The case of 'amount of substance'', *International Journal of Science Education*, 30(10), 1389-1404.

Padilla, K. & Garritz, A. (2011). The Pedagogical Content Knowledge of university chemistry professors teaching stoichiometry, 20 pages. *Proceedings of the NARST 2011 Conference*, Orlando, FL, USA, April 3rd to 6th.

Padilla, K. & Garritz, A. (Submitted 2012). Chapter 'Stoichiometry's PCK of University Chemistry Professors' of the book *Research Based Undergraduate Science Teaching*, Volume 6 of the series Research in Science Education 2012, Published by Information Age Publishers.

Park, S. & Oliver, J. S. (2008). Revisiting the Conceptualization of Pedagogical Content Knowledge (PCK): PCK as Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education*, 38(3), 261-284.

Panksepp, J. (1998). *Affective neuroscience: The foundations of human and animal emotions.* New York: Oxford University Press.

Parkinson, B. & Colman, A. M. (1995, Eds.). *Emotion and motivation,* London and New York: Longman.

Pauling, L. (1960). *The Nature of the Chemical Bond*. Ithaca: Cornell University Press.

Pessoa, L. (2008). On the relationship between emotion and cognition, *Nature Reviews Neuroscience*, 9, 148-158.

Pickering, M. (1990). Further Studies on Concept Learning versus Problem Solving, *Journal of Chemical Education*, 67(3), 254-5.

Pintrich, P. R., Marx, R. W. & Boyle, R. A. (1993). Beyond cold conceptual change: the role of motivational beliefs and classroom contextual factors in the process of conceptual change, *Review of Educational Research*, 63(2), 167–199.

Pintrich, P. R. (2003). A Motivational Science Perspective on the Role of Students Motivation in Learning and Teaching Contexts, *Journal of Educational Psychology*, 95(4), 667-686.

Pintrich, P. R. (2004). A Conceptual Framework for Assessing Motivation and Self-Regulated Learning in College Students, *Educational Psychology Review*, 16(4), 385,407.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change, *Science Education,* 66(2), 211-227.

Reyes, F. y Garritz, A. (2006). Conocimiento pedagógico del concepto de 'reacción química' en profesores universitarios mexicanos [Pedagogical Knowledge of 'Chemical Reaction' concept for Mexican University Professors]. *Revista Mexicana de Investigación Educativa*, 11(3), 1175-1205. Available in the URL http://www.comie.org.mx/documentos/rmie/v11/n31/pdf/rmiev11n31scB02n01es.pdf

Rolls, E. T. (1999). *The brain and emotion.* New York: Oxford University Press.

Rolls, E. T. (2005). *Emotion explained.* Oxford: Oxford University Press.

Salta, K. & Tzougraki, C. (*2011*), Conceptual Versus Algorithmic Problem-solving: Focusing on Problems Dealing with Conservation of Matter in Chemistry, *Research in Science Education*, 41(4), 587-609.

Shulman, L. (1986). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review, 57*, 1-22.

Simpson, R. D., Koballa, T. R., Oliver, J. S. & Crawley, F. (1994). Research on the affective domain dimension of science learning. In D. Gabel (Ed.) *Handbook of Research in Science Teaching and Learning*. (Chapter 6; Pp. 211-234). New York: Macmillan.

Sinatra, G. (2005). The "Warming Trend" in conceptual change research: The legacy of Paul R. Pintrich. *Educational Psychologist*, 40: 107-115.

Southerland, S.A., Sinatra, G.M., Matthews, M.R. (2001). Belief, Knowledge, and Science Education. *Educational Psychology Review*, 13 (4): 325-351.

Spencer, J. N., Bodner, G. M. & Rickard, L. H. (2006). *Chemistry. Structure and Dynamics*, 3rd edition, USA: John Wiley & Sons, Inc.

Sproul, G. (2001). Electronegativity and Bond Type: Predicting Bond Type, *Journal of Chemical Education*, 78, 387-390.

Talanquer, V. (2004). Formación Docente: ¿Qué conocimiento distingue a los buenos maestros de química? [Teachers' Training: Whay Knowledge Characterize to Good Chemistry Teachers], *Educación Química,* 15(1), 52-58.

Talanquer, V. (2005). Recreating a Periodic Table: A Tool for Developing Pedagogical Content Knowledge, *The Chemical Educator*, 10, 95-99.

Teixeira dos Santos. F. M. & Mortimer, E. F. (2003). How emotions shape the relationship between a chemistry teacher and her high school students, *International Journal of Science Education,* 25(9), 1095-1110.

Tomas, L. & Ritchie, S. M. (2012). Positive Emotional Responses to Hybridised Writing about a Socio-Scientific Issue, *Research in Science Education*, 42(1), 25–49.

Van Arkel, A. E. (1949). *Molecules and crystals*. London: Butterworths.

Velayutham, S., Aldridge, J. & Fraser, B. (2011). Development and Validation of an Instrument to Measure Students' Motivation and Self-Regulation in Science Learning, *International Journal of Science Education*, 33(15), 2159-2179.

Vilarroya, O. & Forn i Argimon, F. (2007, Eds.). Social brain matters: stances on the neurobiology of social cognition. Value inquiry book series, Amsterdam/New York: Rodopi.

Wu H.-K.& Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education*, 88(3), 465-492.

Wubbels, T. & Brekelman, M. (1998). The Teacher Factor in the Social Climate of the Classroom. In Barry J. Fraser y Kenneth Tobin (Eds.), *International Handbook of Science Education*. (Chapter 5.2; Pp. 565-580). Dordrecht: Kluwer.

Zembylas, M. (2005). Three Perspectives on Linking the Cognitive and the Emotional in Science Learning: Conceptual Change, Socio-Constructivism and Poststructuralism. *Studies in Science Education*, 41, 91-116.

Zembylas, M. (2007). Emotional ecology: The intersection of emotional knowledge and pedagogical content knowledge in teaching. *Teaching and Teacher Education*, 23, 355–367.

Zimmerman, B. J. (2000). Self-Efficacy: An Essential Motive to Learn. *Contemporary Educational Psychology,* 25, 82-91.

Zoller, U., Lubezky, A, Nakhleh, M. B., Tessler, B., Dori, Y. J. (1995). Success on Algorithmic and LOCS vs. Conceptual Chemistry Exam Questions, *Journal of Chemical Education*, 72, 987-989.