Pedagogical content knowledge with particular focus on chemical bonding concepts and language-based issues

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Abstract: The paper provides a review of the origins and meaning of Pedagogical Content Knowledge (PCK) framework with detailed insight in its five domains (Magnusson, Krajcik and Borko, 1999). Consistent with the author's professional and personal interest, PCK of pre-service chemistry teachers was followed, wherever it was possible. The implications of PCK to Science (Chemistry) teachers' education are elaborated. Through selected examples and explanations, the nature of PCK as it applies to the topic of chemical bonding, with particular insight in the role and importance of language, is presented.

Key words: Pedagogical Content Knowledge (PCK), Chemical Bonding, language of Chemistry, pre-service chemistry teachers

I. TEACHER KNOWLEDGE

It is common in teacher education courses, and in interviews for employment of teachers, that emphasis is placed upon general theories and methods of teaching. Shulman (1986) has asked "Where has the content gone?" He has pointed out that the person who presumes to teach subject matter to children must have knowledge of that subject matter as a prerequisite to teaching. Even more than that, the able teacher should know how to transform subject matter into the content of instruction appropriate for the students, and how particular formulations of that content are related to what students come to know or misconstrue. It was considered necessary to provide a more coherent theoretical framework before probing the complexities of teacher understanding and transmission of content knowledge – a knowledge which refers to amount and organization of knowledge *per se* in the mind of the teacher. We already have a number of ways to represent content knowledge (e.g. Bloom's cognitive taxonomy). Shulman (1986) suggests that we distinguish among three categories of content knowledge: (a) subject matter content knowledge, (b) pedagogical content knowledge and (c) curricular knowledge. These will be discussed shortly.

a) In different subject matter areas, the ways of discussing the content structure of knowledge differ. To think properly about content knowledge requires going beyond knowledge of the facts or concepts of a domain. It requires understanding the structures of the subject matter.

(b) A second kind of content knowledge is *Pedagogical content knowledge (PCK),* which goes beyond knowledge of subject matter *per se* to the dimension of subject matter knowledge for teaching. This is a particular form of the content knowledge that embodies the aspects of content most germane to its teachability. Quality teaching is to a large degree subject-specific: at the very broad level, the aims and skills of teaching literature are different from those required to teach in the sciences. More specifically within the discipline of chemistry, the requirements for quality teaching about bonding are different from those for teaching about stoichiometry. More specifically still, within the topic of chemical bonding, the subject matter related to the nature of covalent bonding needs to be re-packaged in different ways from that related to isomerism in molecular substances. So, PCK is knowledge of quality (effective) teaching of particular topics, concepts, issues and ideas.

(c) The third category is *Curicular knowledge.* The curriculum is represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indicators and contra-indicators for the use of particular curriculum or program material in particular circumstances and refers to consideration of what should be learned, in what contexts, and why.

II. PEDAGOGICAL CONTENT KNOWLEGE

Among categories of teacher knowledge, pedagogical content knowledge is of special interest (Shulman, 1987). Since Shulman's introduction of PCK, the concept has attracted much attention, and has been further developed by numerous science educators. Geddis, Onslow, Beynon and Oesch (1993) defined PCK as "transformation of subject-matter knowledge into forms accessible to the students being taught. They claimed that it is the acquisition of pedagogical content knowledge that makes it possible for beginning teachers to move past a preoccupation with technical competence to a more critical stance involving the transformation of subject matter for teaching. Some researchers directly studied PCK, but a very small number of them have explicitly discussed a particular kind of PCK. Most use PCK as a generic term across several of the subsections. Others didn't mention PCK at all, either because they preceded Shulman's work in the middle 1980s, or used frameworks other than Shulman's to interpret the findings. Still other researchers who have used the PCK framework introduced new constructs into the literature, including the primary science teacher's teachers' term "activities that work" (Appleton, 2002)**,** "pedagogical content concerns" (de Jong, 2000) and "pedagogical context knowledge" as a codified model of teacher knowledge (academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge) situated in school science teaching, proposed by Barnett and Hodson (2001).

Although more or less similar conceptualizations have been made, there is no consensus in the definition or conceptualization of the concept of PCK, and many models of PCK have been proposed (reviewed by, for example, Abell, 2007; Kind, 2009 and Gess-Newsome, according to Bergquist, 2012). Because of the lack of the coherence of the science education PCK literature, I will follow the work of Magnusson, Krajcik and Borko (1999) who expand upon the existing framework of teacher knowledge, which includes the domains of subject matter knowledge (SMK), pedagogical knowledge and knowledge about context, outlined by Grossman (1990), to conceptualise PCK to consist of five discrete components: 1) orientation towards science teaching (knowledge of and about their subject, beliefs about it, and how to teach it), 2) knowledge and beliefs about science curriculum (what and when to teach), 3) knowledge of students' understanding of science, 4) knowledge of assessment in science (why, what, and how to assess), and 5) knowledge of instructional strategies. A deeper look inside each of PCK components (domains) follows.

1. Orientations toward Science Teaching

This component plays a central role in the PCK framework and includes teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular level. This is the general way in which a teacher views the teaching of science and the objectives of instruction. Anderson and Smith (1987) introduced the term "orientation" as a way to categorize disparate approaches to science teaching. Very few studies have examined the connections between teachers' beliefs about teaching, knowledge of teaching, and how these translate into teachers' practice (i.e. orientations). Between them, Zipf and Harrison (2003) examined the dynamic relationship between orientations and practice held by two Australian elementary teachers, Patty and Tina. Patty has much more science teaching experience than Tina, who has worked as teacher for one year only. At that stage in their teaching careers, Patty and Tina hold different beliefs (and orientations as a consequence of it) about what are effective learning experiences in science. Nargund-Joshi and Liu (2013) reported that teachers' science teaching orientations act as filters or amplifiers in shaping teachers' overall classroom behaviours. Analysing teachers' orientations towards science teaching and learning is a first step towards brining change in their classroom behaviours. Nevertheless many research studies were focused on this PCK domain, the concept is still fuzzy and much work more is needed to understand the frameworks that guide science teachers in their planning and implementation of instruction Abell (2007).

2. Knowledge of Science Learners

This component of PCK refer to knowledge that teachers have about student science learning: requirements for learning certain concepts, areas that students find difficult, approaches to learning science, common alternative conceptions (Magnusson, Krajcik and Borko, 1999) and assessments of what they know. The research in this area has concentrated on teacher knowledge of alternative conceptions, teacher images of the ideal science student and more general views of science learning. Nevertheless, some of the studies considered this type of knowledge at a very deep level, regardless of whether it was their main concern. For example, de Jong, van Driel and Verloop, (2005) reported about learning difficulties of pre-service teachers' students concerning the use of particle models to understand the relationship between corpuscular entities and phenomena.

The "Knowledge of requirements for learning" as a subdomain of "Knowledge of science learners" includes teachers' knowledge of prerequisite ideas and skills that students will need to learn a topic. It also includes teachers' knowledge of different approaches that students will use to learn specific content depending on their developmental level and learning style. The subdomain "Knowledge of areas that students find difficult" includes teachers' knowledge of content areas that students will probably find difficult to learn. For example, Garritz, Irazoquel and Izquierdo (2012) reported about difficulties in learning and teaching of chemical equilibrium. Most of these have arisen when students lack the prerequisites for understanding chemical equilibrium or when they have used previous knowledge inappropriately. Bark at al. (2009) reviewed studies in that topic and reported about common misconceptions such as the following: "You cannot alter the amount of a solid in an equilibrium mixture"; "The concentrations of all species in the reaction mixture are equal at equilibrium"; "Large values of equilibrium constant imply a very fast reaction"; "Increasing the temperature of an exothermic reaction would decrease the rate of the forward reaction"; "The rate of the forward and reverse reactions could be affected differently by addition of a catalyst"…

Studies that have looked at teachers' knowledge of student difficulties have found that even when teachers have some knowledge of student difficulties they often lack knowledge that will help students overcome them. One issue surrounding Magnusson's (1999) research is that often teachers are found to hold some of these misconceptions as well as their students.

Several studies examined teacher knowledge of student conceptions within the context of teaching. De Jong and van Driel (2004) reported about the development of pre-service teachers' PCK with respect to their knowledge of difficulties in teaching and learning the multiple meanings of chemistry topics. They emphasized that the opportunity for *learning from teaching*, offered in the initial phase of the program, appeared to be an effective way for evoking the student teachers' awareness of specific teaching difficulties as well as student-learning difficulties. Pinnegar (according to Abell, 2007) found that teachers' knowledge of students came mostly from classroom observations and interactions and that their knowledge increased over time. That was confirmed in several studies. For example, Geddis, Onslow, Beynon and Oesch (1993) found that two student chemistry teachers, in the context of teaching about isotopes, did not realize the difficulties that students would encounter in learning weighted averages, given their familiarity with simple averages. The veteran teacher, in contrast, was able to predict and plan around these difficulties. Akerson at al. (2000) similarly found important differences between how two veteran elementary teachers and a pre-service teacher dealt with student ideas. Experienced teachers viewed children's ideas as perceptually dominated, structured, coherent, experience-based and resistant to change, and repeatedly tried to elicit student ideas. The pre-service teacher, on the other hand, discouraged student expression of their science ideas and focused on eliminating student ideas with the aim of proceeding with "regular" instruction. One of the conclusions was that the experienced teacher with the higher level of content knowledge had the largest repertoire for eliciting and addressing student ideas. De Jong, Ahtee, Goodwin, Hatzinikita and Koulaidis (1999) indicated that pre-service teachers are not very familiar with current pupils' difficulties and concluded that an important task of science teachers should be to take pupils' (pre)conceptions and learning difficulties into account and to negotiate about the meanings of specific concepts.

The research on teacher knowledge of science learning has employed a broad range of methods and lacks cohesion in terms of the research questions addressed. Overall it appears that teachers lack knowledge of student science conceptions, but that this knowledge improves with teaching experience (Abell, 2007).

3. Knowledge (and beliefs) about Science Curriculum

This component can be divided into two categories (Magnuson et al., 1999): (a) knowledge of mandated goals and objectives (e.g., national standards) and (b) knowledge of specific curricular programs and materials. Shulman (1987) considered curricular knowledge, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers, as unique category of the knowledge base, but Magnusson, Krajcik and Borko, (1999) argue for its inclusion, citing that it is knowledge of the curricular materials that divide the content specialist from the pedagogue, which is a defining factor of PCK. Peterson and Treagust (1995) found that knowledge of curriculum was an essential component of pre-service teacher pedagogical reasoning around lesson planning and instruction.

4. Knowledge of Science Instructional Strategies

Hilton and Nichols (2011) reported about findings which suggest that the teacher's approach to selecting, utilising and scaffolding the use of multiple representations is key to the development of students' representational competence and conceptual understanding of complex scientific concepts. There is a need to place greater emphasis on the correct use of multiple levels of representation when describing and explaining chemical phenomena during classroom instruction (Chandrasegaran at al., 2007). Correct use of, for example, multiple levels of representations imply special kind of knowledge about particular resources, instructional strategies and scaffolding – Knowledge of Science Instructional strategies. This component of teacher knowledge includes (a) Knowledge of subject-specific strategies (e.g. demos or labs) and (b) Knowledge of topic-specific teaching methods and strategies, including representations (particular analogies, examples, models, metaphors), demonstrations and activities (labs, problems, cases) (Magnusson, Krajcik and Borko, 1999).

(a) Knowledge of subject-specific strategies includes strategies for teaching the subject of science as opposed to other subjects. Magnusson, Krajcik and Borko (1999) claim that teachers' use of strategies is influenced by their beliefs about the teacher's role in student learning. The level to which a teacher believes an approach to be effective will influence whether they adopt that strategy.

(b) Knowledge of Topic Specific Teaching Methods and Strategies can be divided into two sub-categories (Magnusson, Krajcik and Borko, 1999): i) Knowledge of topic specific representations and ii) Knowledge of topic specific activities.

i) Category of Knowledge of Topic Specific Representations refers to particular illustrations, models, examples and analogies that can be used to represent specific content to students and also knowledge of their respective strengths and weaknesses. Although analogies in science education are welcomed, different opinions about their usefulness have been expressed. Treagust, Duit, Joslinc and Lindauer (1992) concluded from the research results that effective use of analogies in regular classroom science teaching needs to be based on a well prepared teaching repertoire of analogies, using specific content in specific contexts. Van Driel, Verloop and de Vos (1998) suggest a critical discussion concerning the use of analogies and metaphors during the introduction of dynamic equilibrium. Contrary to Treagust, Duit, Joslinc and Lindauer, they hesitate to recommend the use of analogies to promote conceptual change.

ii) The category Knowledge of Topic Specific Activities includes teacher's knowledge of problems, simulations, demonstrations, investigations and experiments and also how these activities will impact student understanding of specific topic. Findings from research have shown that teachers with greater experience generally have more of this type of knowledge than novice teachers. On the other hand, being an experienced teacher is no guarantee that this type of knowledge will be possessed. In contrast to the previous example, de Jong, Acampo and Verdonk (1995) observed the teaching of redox reactions by two experienced chemistry teachers and found that the teachers had many difficulties developing viable instructional strategies. For example, one of categories of teacher problems was overemphasis on the importance of using (algorithmic) procedures as found in textbooks, specifically those with which to balance complex redox half-equations.

5. Knowledge of Science Assessment

This knowledge includes two sub-categories (a) Knowledge of dimensions of science learning to assess and (b) Knowledge of methods of assessment.

(a) This sub-category includes teachers' knowledge of which parts of student learning are the most important to assess in a certain content area.

(b) Knowledge of methods of assessment refers to the way in which a teacher will assess certain aspects of student learning specific to a topic area. The findings in publications which I have access to usually describe methods of assessment in general way. Knowledge of Science Assessment and practice has been emphasized in Kamen's (1996) science teacher's case study. He has found that teacher's perception of assessment shifted toward an integrated model wherein instruction and assessment occur simultaneously. Some of researchers are discussing types of tests or questions, the others are mentioning traditional and/or alternative assessment (Zoller, 2001). As an example of the specific assessment could be provided the one of Zoller (2001) who noticed, that problem (not exercise) solving, critical thinking, system (lateral) thinking and decision-making are not being assessed routinely in most chemistry courses. He reported about example of multicomponent higher-order cognitive skills evaluation questionnaire in the area of energy sources. After reviewing literature about pre-service teacher's knowledge of Science assessment it became obvious that it could be an issue. For example, de Jong, Ahtee, Goodwin, Hatzinikita and Koulaidis (1999) reported that pre-service teachers have only vague ideas about methods and instruments to assess pupils' knowledge and skills. The results of study investigated pre-service chemistry teachers' pedagogical content knowledge of the nature of science (NOS) in the content of the particle nature of matter (Bektas at al., 2013) indicated that while most of the pre-service teachers showed improvement in terms of understanding of the target aspects of NOS in the content of the particle nature of matter, knowledge of learners and instructional strategies, the majority of them did not make progress regarding knowledge of assessment during the study.

After the theoretical framework of PCK has been elaborated, it can be concluded that PCK is more than the sum of these constituent parts (Abel, 2008; Magnusson, Krajcik and Borko, 1999). Teachers not only possess PCK, they employ the components of PCK in an integrated fashion as they plan and carry out instruction.

Although the PCK of pre-service teachers were researched from different points of view: from a case when teacher educator explicitly introduces student teachers to ideas about PCK (Loughran, Mulhall and Berry, 2008), exploration of development of student-teachers' PCK during pre-service education (Nilsson, 2008), study of the development of the Msc. student teachers' PCK of the multiple meanings of chemistry topics (de Jong and van Driel, 2004), to, between many others, learning from teaching through an experimental introductory course module about the use of particle models to help secondary school students understand the relationship between phenomena (e.g., properties of substances, physical and chemical processes) and corpuscular entities (e.g., atoms, molecules, ions) which results with unequal, but noticeable, pre-service teachers' PCK development (de Jong, van Driel and Verloop, 2005), there is little information about what components of PCK pre-service teachers use dominantly. Kind (2013) reported that responses to three vignettes about specific classroom events, one each in chemistry, physics and biology, revealed pre-service science teachers' responses included only three components: representations and instructional strategies; knowledge of students' understandings, and orientations towards teaching. No evidence was found for knowledge of assessment or knowledge of curriculum, or other components researchers have suggested. Further, the range of orientations found was small, and limited mainly to didactic, based on telling, showing, explaining or questioning students, and very small numbers consistent with conceptual change, inquiry, and academic rigour. Cochran (1997) reported that we know very little about how to enhance pedagogical content knowledge in pre-service and in-service programs. Teacher involvement in research and university preparation programs is crucial for the development of this important idea and its usefulness for the improvement of science teaching.

III. IMPLICATIONS OF PCK TO SCIENCE (CHEMISTRY) TEACHER EDUCATION

Talking about PCK as theoretical concept in the broad way in chemistry teacher education programs could be a shot in dark. Much more important is, in my opinion, to deal with PCK in a way that expressed its essence – a special kind of knowledge of transformation of particular parts of SMK in the forms of clearly and understandable teaching and learning sequences which (probably) fit the best in the particular circumstances. So, courses or coursework should be based on concrete examples recognised in our classroom practice and/or published chemistry teachers' and researchers' findings and some, not broad, generalisations and/or recommendations. For example, van Driel, de Jong and Verloop (2002) present a number of implications for science teacher education derived from their study. Firstly, they recommend organizing specific field-based activities. In particular, the pre-service teachers could be asked to analyse their students' answers to written tests or specifically designed assignments in terms of students' learning difficulties. Secondly, the use of articles from the educational research literature in university based workshops is recommended, provided that the timing and the format of these sessions enables the pre-service teachers to relate their own experiences and beliefs to such articles. Finally, the role of the mentors should be given special attention. The observed variation in the mentors' approach and involvement indicates that they potentially have a strong impact on the development of pre-service teachers' PCK. Bucat (2004) reported that there already have been attempts to describe pedagogical content knowledge pertaining to particular chemistry topics which refer to the content-related demands of teaching about the topics of isotopes, thermodynamics, oxidation-reduction chemistry and chemical equilibrium (van Driel, Verloop and de Vos, 1998) respectively. I have searched for evidence of PCK concerning Chemical bonding concept. A few examples are elaborated in next section.

IV. PCK ABOUT CHEMICAL BONDING

While chemistry is one of the most important branches of science and has been regarded as a difficult subject for young students by chemistry teachers, researchers, and educators (Özmen, 2004), chemical bonding is one of the most important subjects (Coll and Treagust, 2001) and a key concept in chemistry (Taber and Coll, 2002). It is considered a core topic in many chemistry curricula at school, college and university level (Taber and Coll, 2002). Understanding chemical bonding is important to comprehend the nature of the chemical reactions, thermodynamics, molecular structure, chemical equilibrium and some physical properties such as boiling points. Also, reactivity, spectroscopy and organic chemistry concepts cannot be understood unless students understand the chemical bonding theories (Pabuçcu and Geban, 2012). However, it is also a topic where learners commonly develop a wide range of misconceptions (alternative conceptions) (Barker, 2000; Barker and Millar, 2000; Nicoll, 2001; Taber, 2002; Özmen, 2004; Barke, Hazzari and Yitbarek, 2009; Ünal, Coştu and Ayas, 2010; Taber, 2001; Taber, Tsaparlis and Nakiboğlu, 2012). Recognition and awareness of such students' (learning) difficulties and thoughtful and carefully planned teaching and explaining content based strategies as a way to combat them, are only few of many PCK considerations of bonding concept.

Taber and Coll (2002) have organized a book chapter about bonding on four pedagogic learning impediments: (1) learners hold an incorrect and inappropriate rationale for why bonding should occur; (2) learners see all bonding as involving discrete molecules, and do not understand the nature of ionic and metallic bonding and of giant covalent structures; (3) learners may discount from the category of "bonding" anything which does not seem to fit the description of "electron sharing" or "electron transfer"; (4) learners may be unable to make sense of intermediate bond types (e.g. polar bonding). Taber and Coll (2002) considered Bonding in terms of the following principles: (1a) The chemical bond is due to electrical forces; (2a) Bonding need not imply molecules; (3a) Not all chemical bonds are covalent or ionic, and (4a) Bonding may be intermediate between covalent and ionic. Let's take a more detailed picture of listed learning impediments.

1) Students are found to commonly use the octet rule as the basis of a principle to explain chemical reactions and chemical bonding. According to this „full shells explanatory principle", bonding occurs „in order (for atoms) to try to achieve a stable structure (*i.e.* 8 electrons in the outer shell of the atom)". Students relate the „sharing" of electrons in covalent bonds to the full shells explanatory principle, so that „the electrons are shared to create a full outer shell", and the „covalent bond is the sharing of electrons to complete full valence shells" (Taber, 2002). Ionic bond is similarly understood as „where you donate or gain electrons, to form a completed outer shell". It is founded that „the full shells explanatory principle" may also be invoked in students' explanations of metallic bonding (Taber, 2012). It can been seen from the previous that "the full shells explanatory principle" is inherently anthropomorphic. The researched literature (as well as my experience) suggests that anthropomorphic language is part of student's explanations (as well as teachers' and even those in textbooks). But, is that an issue? Taber and Watt (1996) postulated a hypothesis: If strong anthropomorphism is just a stage in developing understanding, then one might expect anthropomorphic language to diminish as other levels of explanation become available. Dorion (2011) supported it with findings that it is not age, but the degree of one's knowledge, that indicates the tendency to use teleological anthropomorphisms, and that anthropomorphic analogies may be a first response of the learning mind when confronted by a lack of understanding, or inability to recall previous knowledge.

2) From the modelled chemistry view, some materials with covalent bonding will exist in the form of molecules, but others may have extensive covalently bound lattices. Metals and salts do not consist of molecules, but of ions, which are bonded together. Such diversities sometimes is not recognised - many students tend to conceptualise bonded materials as always being in the form of molecules (Taber and Coll, 2002). Usually the first and the most familiar context of chemical bonding to students – the concept of covalent bonds in small discrete molecules – could be the source of such difficulties if the nature of bonds is not understood well. One approach which could help with this problem, as a part of PCK, was provided by Nahum, Mamlok-Naaman, Hofstein and Krajcik (2007). They noticed that curriculum developers classify substances according to a "list of properties" into four different groups of lattices (ionic, molecular, covalent, and metallic) and elaborate on and discuss each of these structures based on the chemical bonds that exist between the particles. These types of chemical bonds (ionic, covalent, and metallic) are often discussed as different entities which can cause learning impediments. They proposed new approach which is based on an understanding of the common principles and concepts suggested for all chemical bonds and then use these ideas to explain the structures and properties of molecules and lattices.

3) There are more than one dichotomy considering chemical bonding. Nahum, Mamlok-Naaman, Hofstein, and Krajcik (2007) reported that elements, in many chemistry textbooks, are conveniently classified as metals or non-metals; and sometimes a few semimetals are mentioned. Very often, this dichotomy among elements leads to a dichotomous classification of bonding related to compounds: covalent being between non-metallic elements and ionic being between a metal and a non-metal. Research suggests that students at the end of secondary education commonly know about two separate categories of chemical bonding - covalent and ionic -

which are often followed with alternative conceptions - where students often come to see the covalent bond in terms of an inadequate image (electron sharing) they often define ionic bonding in terms of a completely irrelevant notion: electron transfer (Taber, 2002). Once a bonding dichotomy scheme has become established the students find it difficult to appreciate bonding that is intermediate (polar bonds) or which falls outside (e.g. hydrogen bonding) this narrow definition of bonding (Taber, 2002).

4) In the light of the concept of polar covalent bonding, Harrison and Treagust (1996) indicated that polarity of molecules, the bond polarity and shape of molecules could be issues for students. The reason for this, according to Taber and Coll (2002), could be confusion over the understanding of electronegativity and presenting ionic and covalent bond as a dichotomy. Where students think about bonding in terms of the dichotomy they will tend to describe a polar bond as a modified covalent bond, rather than something intermediate between covalent and ionic. However, unless the bond polarity is drawn to their attention, it is quite likely they will ignore it completely (Taber, 2012). This tendency to ignore bond polarity leads to other errors. For example, as students tend to classify hydrogen fluoride as covalent, rather than polar, they often describe the solvated species to be hydrogen fluoride molecules when it dissolves in water. Bergquist (2012) suggests that findings about textbooks' clarity in how polar covalent bonds are related to polar molecules might be a source of confusion about these concepts.

As chemical bonding is a key concept in chemistry, it is also a topic where understanding is developed through diverse models – which are in turn built upon a range of physical principles – and where learners are expected to interpret a disparate range of symbolic representations standing for chemical bonds (Taber and Coll, 2002; Coll and Taylor, 2002). Students are expected to develop an understanding of these models and to interpret a variety of representations for chemical bonds (e.g., chemical formulas, ball-and-stick models, etc.). If we look at Chemistry generally, diverse (type of) symbols are often used to represent macro phenomena and the submicro entities (Cheng and Gilbert, 2013). Also, scientists and learners construct mental representations to interpret their experiences and to make sense of the physical world (Coll and Treagust, 2003a; Coll and Treagust, 2003b). The careful usage of verbal language, i.e. the spoken and written word, is more than just important for communicating with all those representations. But, students are not only expected to learn the ideas represented (only) verbally, they are also expected to manipulate and create mental visual representations at the macro and submicro levels (Bucat and Mocerino, 2009). Without any doubt, words are important, but in chemistry (probably) more than any other subject we rely on a combination and interaction of words, pictures, diagrams, images, animations, graphs, equations, tables and charts. They all convey meaning in different ways – they all have their own importance and their own limitations (Wellington and Osborne, 2001). All of them are part of the language – a major barrier, if not the major barrier, to most pupils in learning science.

V. LANGUAGE – A PREREQUISITTE FOR SUCCESSFUL TEACHING AND LEARNING

Learning the language of science is a major part, if not the major part, of science education. Every science lesson is a language lesson (Wellington and Osborne, 2001). That fact is even more emphasized in the topic of chemical bonding. Because of concept abstraction and modelled foundation, the teaching and learning language could be a source of problems in understanding. Some of them are associated with the misunderstanding of common language used in a science context (Johnstone and Selepeng, 2001). The conclusion that teachers with any class must be careful to check that the meanings of "obvious" words are shared by students and teachers was supported by finding that lots of students don't understand the meaning of the "simple", everyday words like *initial*, *abundant*, *effective* or *adjacent*. Some words have different everyday and science meaning, sometimes fully opposite. For example, dispersion forces in chemistry are the forces which keep particles together. In other aspects of science and life, *dispersion* means spreading. "It is PCK to realise that the term dispersion force may provide some confusion for chemistry students because in everyday usage the term *dispersion* means to spread out" (Bucat, 2004). The meaning of the other words could be well known (or maybe not), but if we use them allegorically, the real meaning could be misunderstood. For example, for some students, the bond is the sharing of electrons – and this is not necessarily meant figuratively. The teacher may talk of a shared pair of electrons as a shorthand for the electrical interaction, but too many students "sharing" electrons is a technical and not a metaphorical description of the bond. Sharing is "social" process not a physical one. (Taber, 2012). Even more, the word "sharing" could be a language issue because its duality meaning also: a) sharing as something which allows two or more sides to be in the property, and b) sharing as a process of division (splitting). Again, it's PCK to recognize the problem and to provide useful (language) strategies for avoidance or resolution of it. When we know that common terms with special meaning in the chemistry context could be issues, it is not difficult to realize what problems could be caused if pupils don't know or don't understand the meanings of chemical symbols, formulas and equations, technical jargon, diagrammatic symbols, molecular structure representations, expressions of quantitative relationships, graphical presentation of data and others language of chemistry forms. All of them should be used and combined synergistically in the purpose of understanding causes and consequences in nature and constructing adequate student's mental images and models of chemical world. Those images are much more than textbook pictures (Bucat, 2013), which are often (between all representations) insufficient and sometimes misleading, but through careful communication, could be helpful in appropriate mental images development. For example, surely the common textbook representation of a gas with its static molecules, and extremely inaccurate representations of spacing's between the molecules is not what we hope that students will „take home". Seldom can a picture on its own initiate the mental image that we hope a student will develop: some form of language as captions, labels, or voice are necessary, and we need to be careful with the language of these aids (Bucat, 2013). If we are not, some of the language that chemistry teachers commonly use has the potential to confuse students by not clearly distinguishing between whether we are talking about the macroscopic level or the sub-microscopic level of atoms and molecules (e.g. Copper is malleable because its atoms are malleable; Nitrogen gas expands on heating because it molecules expand.) (Bucat, 2013).

Bent (according to Bucat, 2013) describes well how complicated the role of language in Chemistry is, comparing Chemistry itself with a foreign language: "Chemistry is a foreign language twice over: Strange terms for strange things". On the other hand, Postman and Weingartner (1971) wrote: Almost all of what we customarily call "knowledge" is language, which means that the key to understanding a subject is to understand its language. In fact, that is a rather awkward way of saying it, since it implies that there is such a thing as a subject, which contains language. It is more accurate to say that what we call a subject is its language.

In conclusion, the topic of chemical bonding is a special part of chemistry (education) for which we need specific language to communicate with, along with common and technical language. Beside language, because of the abstract nature of the many overlapping models of the topic (which also involve language issues), many well-documented alternative conceptions of students have been identified, so PCK about chemical bonding is of special research interest. Particular attention to pre-service teachers could be achieved through investigation of their PCK about chemical bonding and, based upon the research findings, new teaching and learning approaches and methods could be implemented. This could lead to a complete curricular reconsideration.

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