Evidence of development of PCK related to chemical bonding during a course for pre-service chemistry teachers

Abstract

The impression that many pre-service chemistry teachers are demonstrating issues in application of their Pedagogical content knowledge (PCK) in teaching practice, especially in the area of fundamental chemistry topics, serves as motivation for changes of Chemistry Education 2 course curriculum. For the purpose of stimulation of PCK the course is changed in following areas: intending learning outcomes, the language of chemistry instruction, awareness of "Johnstone's triangle" of operations and common alternative conceptions. To obtain evidence of pre-service teachers' in-practice PCK about chemical bonding, especially PCK related to the revised areas of Chemistry Education 2 course, we designed and conducted a case study based on detailed monitoring of one pre-service teacher's pre-teaching, teaching and teaching evaluation activities. The findings demonstrate evidence of growth of the preservice teacher's PCK about chemical bonding, with particular characteristics that indicate that their source is almost certainly the revised Chemistry Education 2 curriculum.

Key words: chemical bonding, Chemistry education course, pedagogical content knowledge (PCK), pre-service chemistry teachers

<u>Introduction</u>

Current research in Chemistry Education in Croatia

In Croatia, research studies in chemical education have mainly been conducted by postgraduate students enrolled in the *Research in education in the field of natural and technical sciences* doctoral study program at the University of Split, as well as their mentors and colleagues.

Several authors have presented their findings through press releases, at scientific conferences, and as articles in national journals. A few papers have had a wider distribution in journals that can be found in international science databases.

Two of the international papers (Vladušić, Bucat and Ožić, 2016a and Vladušić, Bucat and Ožić, 2016b) are related to the concept of pedagogical content knowledge (PCK) in the Croatian chemistry education context. PCK has come to be recognised as perhaps the most important part of the armoury of successful teachers.

The motivation for the research reported here was the belief that programmes for education of pre-service teachers should include arousal of the importance of PCK – that is, knowledge beyond content knowledge and content-independent pedagogical knowledge.

University professors have perceived that in the past, even when pre-service teachers showed evidence of good chemistry knowledge and good pedagogical knowledge, many demonstrated deficiencies of PCK in their teaching practice, even with regard to fundamental chemistry topics. Traditionally, recognition of the importance of PCK, and accumulation of a store of PCK, has been derived only from experience as teachers.

At the University of Split, a pre-service teacher education programme has been designed to develop the PCK of the enrolees, particularly with respect to the topic of chemical bonding.

We have chosen to present insights into the efficacy of this course insofar as it has influenced the PCK of one participant. The research undertaken is in the form of a case study - a story of the experiences and thinking processes of one pre-service chemistry teacher.

Pedagogical Content knowledge

Shulman (1986) proposed distinguishing three categories of teacher's knowledge: (a) knowledge of the content, (b) pedagogical content knowledge (PCK) and (c) knowledge of the curriculum.

Among those categories, PCK is of particular interest (Shulman, 1987). PCK is specific form of knowledge based on translation of content knowledge (for example, Chemistry) to content knowledge for teaching. More specifically, PCK is a knowledge of effective teaching of particular topics, concepts, issues and ideas.

Since Shulman introduced PCK, the concept has attracted a great deal of attention from both teachers and researchers, so its development has continued intensively. Geddis, Onslow, Beynon, and Oesch (1993) defined PCK as transforming knowledge of subject content into forms adapted for student teaching. Bromme (1997) reflects on PCK as the knowledge and skills necessary for the conversion of content items in the content adapted to lecture students, emphasizing that way of teaching is independent of the content that we will present.

At the turn of the century, in the 1990s and early 2000s, new directions for the conceptualization of PCK emerged. Some scholars have emphasized the role of PCK in action (Cochran, De Ruiter and King, 1993; Van Driel, Verloop and de Vos 1998, 2002), while others present PCK as a set of knowledge from multiple fields and emphasize its role in prancing and evaluating teaching itself (Magnusson, Krajcik and Borko, 1999).

In last decade major changes brought by first PCK Summit held in 2012. Thanks to inconsistent models and different research methods, the PCK Summit has identified weaknesses that have theoretically and practically limited the usefulness of PCK in this field (Carlson, Stokes, Helms, Gess-Newsome and Gardner, 2015). The result of a multi-day discussion has resulted with a model of teacher professional knowledge (Gess- Newsome, 2015).

Over the years, various models have evolved that occasionally diverge from the original Shulman's idea. We still can't say that there is a consensus regarding the PCK model. The one of the most accepted is the Magnusson *et al.* s' PCK model (1999) built by five discrete components: 1) orientation towards science teaching, 2) knowledge and beliefs about science curriculum, 3) knowledge of students' understanding of science, 4) knowledge of assessment in science, and 5) knowledge of instructional strategies. Because its intrusiveness we will follow Magnusson's PCK model in this paper.

The research context: Design of a pre-service teacher education programme

At the Faculty of Science, University of Split, pre-service chemistry teachers enrol in a programme entitled *Diplomski sveučilišni studij Biologija i Kemija – nastavnički smjer* (approximately, *University Diploma study in Biology and Chemistry - teaching stream*). Within this programme, those preparing to be school chemistry teachers undertake five courses, listed here in the order in which they are presented over three semesters: (i) Metodika nastave kemije 1 (Chemistry education 1), (ii) Praktikum iz metodike nastave kemije 1 (Laboratory in Chemistry Education 1), (iii) Metodika nastave kemije 2 (Chemistry Education 2), (iv) Praktikum iz metodike nastave kemije 2 (Laboratory in Chemistry Education 2) and (v) Metodička praksa (Teaching practice).

From our teaching experience and awareness of the chemical education literature, we recognised four specific aspects of chemistry-based PCK in which the students seemed to be deficient: a) intended learning outcomes, b) the importance of the "chemical triplet" (or "Johnston's triangle"; Johnstone, 1982), c) the hazards associated with the commonly used language of chemistry instruction (Markic and Childs, 2016; Vladušić *et al.*, 2016b) and d) awareness of alternative conceptions commonly held by school students that is, beliefs and explanations that are not consistent with accepted science (Barker and Millar, 2000; Boo, 1998; Coll and Treagust, 2003; Taber, 2002; Vladušić *et al.*, 2016a).

This motivated us to re-design the curriculum of the Chemistry Education 2 course in a way to raise the pre-student teachers' awareness of these issues (a) to (d) above, and to conduct research to look for evidence that the revised course had influenced the pre-service teachers' PCK in practice.

Because of the abstract nature and fundamental importance of chemical bonding, and previous research that highlighted the challenges related to teaching in this topic (Vladušić *et al.*, 2016a), we decide to focus this intervention on the pre-service teachers' PCK of chemical bonding models.

Design of the revised Chemistry Education 2 course

The curriculum of the Chemistry Education 2 course was changed so that emphasis of content was decreased with respect to the psychology of learning, sources of knowledge and presentation instruments, types of "teaching lessons", and evaluation issues. Instead, the course now involves more extensive and more focused considerations of the four aspects, referred to above, and described in more detail here:

a) ***Intended learning outcomes***

Until few years ago, the Croatian educational system was based on teaching tasks, rather than on intended learning outcomes. Because the change of paradigm from tasks to outcomes by teachers was more difficult than expected, this topic was included in the revised course.

Intended learning outcomes are firstly taught theoretically with emphasis on their importance, algorithms of writing, focus at the different levels and types of knowledge and abilities, and to their evaluation. After that, pre-service teachers are involved in writing and evaluation of intended learning outcomes through two workshops.

b) ***The language of chemistry instruction***

This aspect was initially presented as a review of evidence from the literature regarding the importance of careful use of chemistry language. In the revised curriculum we introduced an original teaching and research method called OZO (Vladušić, 2017) for enhancement of pre-service teachers' awareness of language of chemical instruction complexity and specific issues, as well as for diagnosis of PCK changes. It is based upon the use of two questionnaires: one designed to indicate students' expectations regarding the complexity of particular terms, and the other designed to evaluate the students' understandings of those terms.

Also, special attention is given to the meanings of scientific and non-scientific words, words with more than one meaning, and symbols used in chemistry instruction (Vladušić and Ožić, 2016), followed by discussion about the complexity of their meanings, and pre-service teachers expectations of students' understandings.

c) ***Awareness of the "Chemical triplet", or Johnstone's triangle***

The “chemical triplet”, first suggested by Johnstone (1982) refers to chemists’ operations at the levels of (i) macroscopic, observed phenomena, (ii) a sub-microscopic modelled world of explanation, and (iii) the symbolic language. Although the chemical triplet was a part of the old curriculum, many pre-service teachers demonstrated weaknesses in its application in teaching practice. In the revised curriculum, after theoretical consideration of the chemical triplet, and before teaching praxis, pre-service teachers were asked to design teaching scenarios with focus on the chemical triplet, and to explain the connectivity (and distinction) between levels of the triplet.

d) ***Common alternative conceptions***

During the Chemistry Education courses it was noticed that pre-service teachers have some alternative conceptions. This has been demonstrated with research focused on pre-service teachers’ understandings of covalent bonding models (Vladušić, 2017) and the ionic bonding model (Vladušić *et al.* 2016a).

Trying to reconstruct the understandings of the pre-service teachers, we created a specific teaching (and research) strategy based on cognitive conflict, called *Open interview* (Vladušić, 2017). The strategy is based on a partly structured conversation on a pre-determined topic between two pre-service teachers, observed by others. Communication was led by questions, claims and graphics. At specific moment the observers were invited to participate in the discussion.

The research: Overview and research questions

We designed and conducted a qualitative research study to obtain evidence of pre-service teachers’ in-practice PCK with respect to chemical bonding, with proofs of potential development of their PCK gained by learning and teaching.

The research is based on monitoring the pre-service teachers’ pre-teaching, teaching and teaching evaluation activities, and is led by research questions 1 (RQ1) and 2 (RQ2):

1. What evidence can be detected of development of the pre-service chemistry teachers' PCK about chemical bonding that can be attributed to participation in that component of the Chemical Education 2 course that was designed for the purpose of stimulation of PCK?

2. What other evidence can be detected of the pre-service chemistry teachers' PCK about chemical bonding that cannot be directly attributed to participation in that component of the course re-designed to stimulate PCK (and must be an outcome of the preceding components of the Chemical Education programme)?

Methodology

A case study approach

Sixteen pre-service chemistry teachers enrolled in their last year of the Biology and Chemistry graduate study program at the University of Split, Faculty of science, were involved in this research. Each of them performed one teaching lesson in the first-grade class (15 years old students) of the Gymnasium. Because we wanted to get deeper insight into a personal story we decide to select one of them as a case study.

This student’s understandings and thinking processes were monitored in considerable detail during her teaching (preparation, praxis, and testing) in the topic Introduction to chemical bonding. For ethical reasons, we use a false name, Antonia.

Yin (2014) recommends that case study is the preferred method when (i) the main research questions are "how" or "why" questions, (ii) the researcher has little or no control over behavioural events, and (iii) the focus of study is a contemporary phenomenon [occurring in a real-world context]. All of these conditions apply in this study. Although one might argue that the researchers have influenced behaviour through the design of the course, in fact the new course is the real context and the researcher has no control over how the subject reacts to instances within that context: they can only investigate "How?" or "Why?"

Within the constraints of limited resources it was decided that the most valuable outcome could be derived from deep-level, forensic monitoring of just one student, rather than to more superficially monitor more students – the extreme case of which is a survey. In this way, the researchers expected that evidence for the interaction between nature of the course and the teacher's PCK growth would be insightful, even if not representative.

The selection of Antonia as the subject of study was entirely a matter of opportunity and circumstance: she had often demonstrated good analytical awareness of her thinking and understanding, and was relatively uninhibited in discussing them. Furthermore, she volunteered to participate.

Coincidentally, based on her previous performances in chemistry, Antonia could be described as a "middle-of-the-road" student. This is not to imply that the researchers regarded her as a statistical average of the whole class, or in some way representative of the total class.

No attempts were made to compare the PCK development of Antonia with other students, either within the class or to students external to the class.

This case study was not concerned with comparability between students or groups of students, and we make no claims about the degree of commonality between the critical features that were influential in Antonia's PCK development, and those that might have influenced the development of others.

Rather, it was an exploratory study searching for evidence that the newly designed curriculum had indeed influenced Antonia's PCK, identifying circumstances under which such development occurred, and trying to understand the nature of Antonia's interactions with teaching situations that gave rise to increased PCK.

It may well be the starting point for further studies that compare how different classes of people (classifications based on gender, or previous grades, or personality types, for example) interact with particular situations designed to engender PCK.

Instruments

During the research pre-service teachers were involved in following activities: a) analysis of the sequence of teaching units within the Chemical bonding chapters in the textbook, and reflection upon how the sequence might be improved, b) completing a lesson preparation sheet, c) performing a teaching lesson, d) reflection and self-evaluation of teaching and e) evaluation of colleagues' teaching.

Here are more details about the instruments.

a) Pre-service teachers' analysis of sequencing in textbook Chemical bonding chapters, with reflections and decisions reported on a blank paper, supported by arguments and justifications.

b) A lesson preparation sheet was designed in such a way that pre-service teachers needed to think about and express lesson goals, alternative conceptions published in the scientific literature, lesson-related terms which the pre-service teacher expected the students would already know, new terms which should be introduced during the lesson, intended learning outcomes, questions for evaluation of the intended learning outcomes, possible limitations and obstacles, critical analysis of textbook content related to the lesson, big ideas, relevant examples of the distinction between the macroscopic and sub-microscopic worlds, elaboration of the sources of knowledge and key terms, the flow of teaching and learning activities, a plan of blackboard usage, and emotional prediction (about classroom atmosphere).

c) Teaching lesson performances were video recorded for analysis and evaluation.

d) A self-evaluation sheet was required to be completed within one day after teaching performance. Furthermore, each pre-service teacher was expected to give a final review of her/his performance and recommendations of possible improvement.

e) As well as the pre-service teacher who was engaged in practice teaching, at least 7 colleagues were present to keep field notes which they were expected to use in evaluation of the teaching performance.

The evaluation of teaching instrument (sheet) had two parts: the first was taken from the Handbook for Observation and Improvement of Teaching (Bezinović, Marušić and Ristić Dedić, 2012.) and had 31 general question related to classroom performance, each with 5 answer choices, and the second requires expression of personal impressions of the teaching quality, aspects which were highly rated as well as aspects which could be improved, and self-evaluation of development of their own PCK related to chemical bonding.

Results organisation

The achievement of the pre-service teacher is expressed as a story. The story is guided by data collected with research instruments in following order: teaching units' sequencing, lesson preparation sheet, teaching performance, self-evaluation of teaching and evaluation of teaching. PCK evidences related to the four revised areas of the Chemistry Education 2 curriculum has been searched in all instruments' data. However, they are dominantly presented and discussed in *teaching performance* paragraphs because we are very interested to correlate Chemistry Education 2 revised curricula and pre-service teacher's PCK shown in teaching practice. PCK evidences are recorded and classified according to the domains of Magnusson *et al. s'* (1999) PCK conceptualisation.

Results and discussion

Story about Antonia's thinking and her experience

Antonia had demonstrated middle-of-the-road achievement in Chemistry Education courses. She was responsible and committed. At the beginning of Chemistry Education 1 course, Antonia demonstrated a traditional view of teaching – that is, she chose teaching scenarios[1] mainly based on chalk, blackboard and teacher's didactic verbal presentation.

[1] At the beginning of pre-service chemistry teachers' enrolment in the first Chemistry Education course – Chemistry Education 1, they were engaged in fulfilling a questionnaire which consisted of tasks with different teaching scenarios. Results of that questionnaire served to note pre-service teachers' starting points in regarding chemistry teaching issues, and to follow their progress during and after fulfilling all obligations related to Chemistry Education courses.

Sequencing of the teaching units

The pre-service teachers analysed the order of teaching units in the two relevant chapters of the school textbook. In the chapter *Chemical bonds* the units were in the order “What is a chemical bond?”, “The covalent bond”, “Arrangement of atoms in molecules”, “Exceptions to the octet rule”, “Polarity of molecules”, “Intermolecular forces”, “Ionic bond”, and “Metallic bonding”. In the following chapter *Crystals*, the units were “Type of chemical bond and the properties of crystals”, “Metallic crystals”, “Ionic crystals”, “Molecular crystals”, and “Atomic crystals”.

Antonia was reasonably satisfied with the order of the units. However, she proposed some relatively small changes, because she thought large-scale reordering could cause difficulties for students to manage the textbook content.

She decided that she would introduce exceptions to the octet rule before the unit on the arrangements of atoms in molecules, so that *students will be able to understand how atoms in molecules with trigonal bipyramid or octahedral shape are arranged.*

Also, she would teach about atomic and molecular crystals after intermolecular forces, but before ionic bonding, so that *students would be able to connect the covalent bond model and intermolecular forces with the macroscopic properties of atomic (covalent) and molecular crystals.*

Ionic crystals, she wrote, *I would teach after ionic bonding. In that way students will connect macro and sub-micro worlds.*

By re-ordering teaching units, or segments of units, Antonia had demonstrated knowledge about the science (Chemistry) curriculum (Magnusson *et al*., 1999). According to Sibandas (2018), the way teachers sequence chemistry lessons can be an indicator of teachers’ topic-specific professional knowledge according to the PCK model of Gess-Newsome (Gess-Newsome, 2015). This sensible re-ordering of teaching units is a partial response to RQ2.

Besides that, and in accord with RQ1, Antonia has shown awareness of the chemical triplet and understanding how the levels of representations should be distinguished in the area of chemical bonding. The way a teacher presents chemistry through the triplet relationship corresponds to the knowledge of representations (Adams, 2012), so this observation we judged as an evidence of Antonia’s PCK development in the domain of Knowledge of science instructional strategies, and more specifically as an evidence of her Knowledge of topic-specific teaching methods and strategies, including representations (Magnusson *et al.*, 1999).

Lesson preparation sheet

Antonia’s allocated lesson was *Introduction* to *chemical bonding*. In general, Antonia prepared a teaching plan for dynamic, interactive instruction, with focus on important questions (big ideas). In the following discussion we focus our attention on particular points related to RQ1.

Firstly, in the scientific literature, Antonia identified a few common alternative conceptions about chemical bonding related to her lesson. However, none of these were about reasons why bonding occurs. Always, and especially in cases like this one, when teacher knows nothing about her students’ knowledge, awareness of common alternative conceptions recognised by others could be helpful. That kind of knowledge identified by Antonia can be considered to belong to the PCK domain *Knowledge of science learners* (Magnusson *et al.*, 1999). Although its importance is obvious, it is unreasonable to expect that a pre-service teacher, especially one with no in-service experience, would have this type of PCK at a higher level.

Antonia's textbook analysis was very good. She recognised instances of anthropomorphism, such as *"...atoms feel...",* and "*Atoms of other chemical elements combine together to fulfil its valence shells."* She considered the latter sentence to be misleading because *"there is no explanation that atoms are combining to achieve the state with the lowest energy level"*. Although this could be considered as evidence of her PCK, it is in contradiction to an intended learning outcome that she wrote: "S*tudents will understand octet rule as a model used for chemical bonds formation explanation".*

Antonia set three intended learning outcomes: a) *Students will understand the nature and reasons for chemical bonding formation; b) Students will understand octet rule as a model used for chemical bonds formation explanation and c) Students will be able to represent atoms with Lewis symbols.*

The intended learning outcomes were set on big ideas, but, as we just few lines above described, one of them was based on an alternative conception, while two of three Antonia's intended learning outcomes were expressed with imprecise verbs (such as "*will understand"*). For example, shaped more precisely expressed intended learning outcome a) is *Students will be able to explain the nature of chemical bond and why bonding occurs*.

Regarding awareness of chemical language which could be recognised in Antonia's lesson preparation sheet, it was obvious that she gave it appropriate importance. All key terms were classified into two groups according to their novelty for students (new ones, or previously introduced ones). Some of them were imagined as focal points for discussions, for example, led by the instruction: "*Please, define the term 'interaction'"*. Because it was effective, we consider this to be evidence of development of Antonia's PCK domain *Knowledge of science instructional strategy* (Magnusson *et al.*, 1999).

Once again, Antonia has shown PCK related to valid usage of the chemical triplet and demonstrated Knowledge of science instructional strategy (Magnusson *et al.*, 1999). More specifically, she planned to start a lesson focusing on water as a substance and moving the focus gradually to molecules of water, asking questions such as: "*Why is our planet called a blue planet?", "What is water?", "What holds water molecules together?" "What atoms build water molecules?" "What holds the atoms in water molecules together?"*.

Teaching performance

After completing the lesson preparation sheet, Antonia presented the lesson in school. The lesson was video recorded. Here is a short analysis of Antonia's accomplishment.

Antonia performed a teaching lesson based on a heuristic approach. She asked lots of questions which include the word *why*. Sometimes, she wasn't patient enough, and answered the questions. Some students actively participated in the class. However, the class consisted almost entirely of student-teacher communication. Even discussions about her questions did not provide opportunities for student-student interaction. The lesson was divided into three mini blocks. After each of them, Antonia evaluated the students' knowledge.

It is not possible to draw conclusions about a teacher's orientation from one teaching lesson, but it seemed that Antonia had moved away from the traditional view of teaching presented at the beginning of the Chemistry Education 1 course to a more preferable heuristic approach.

In following paragraphs we will give attention to evidences of Antonia's PCK demonstrated during her teaching, with focus at four changed areas of the revised Chemistry education 2 course.

Learning outcomes

We had the impression that Antonia's students had a reasonable level of understanding about the nature of chemical bonds and reasons why chemical bonding occurs. However, many of them didn't become able to write examples of atoms represented by Lewis symbols, and couldn't fully explain Lewis symbol connectivity with an atom's electronic configuration using drawings of atomic orbitals. As might be expected of an inexperienced teacher, in the specific context regarding teaching content and limited lesson time, Antonia didn't introduce the most appropriate examples of atoms for drawing Lewis symbols.

Namely, her plan was to, just before the end of the class, introduce Lewis symbols using a few simple examples. In each example she decided to connect the Lewis symbol of an atom with the atom's electron configuration and its orbital distribution (she drew valence orbitals of an atom and placed electrons in orbitals), and to discuss the number of bonds an atom can establish in a molecule. She started with the example of an oxygen atom and followed with examples of carbon, beryllium and boron atoms – all three of them need to be supported with the simplest explanation of how atomic orbitals are imagined to form hybrid orbitals.

For example, when Antonia introduced a carbon atom Lewis symbol, and drew 2s and 2p orbitals and filled them with electrons, the students became confused as to why there is not a pair of dots and two single dots around the symbol for a carbon atom in its Lewis symbol when there is one full 2s orbital (with two electrons) and two 2p orbitals with single electron in each of them. And so Antonia mixed the orbitals, moving one electron from a 2s orbital into an empty 2 p orbital, and explained that a carbon atom can use four single electrons for forming four bonds.

All of this was very challenging for students and they have asked Antonia to explain it once more with a new example. Trying to help the students, she offered a new challenge - the example of phosphorus atom's Lewis symbol, and made a mistake. A student called to draw a Lewis symbol of a phosphorus atom on the blackboard did it successfully, but Antonia asked him to draw valence orbitals of a phosphorus atom and move one 3s electron to the first free d orbital. The student did what she asked and tried to verbally link the electronic configuration of a phosphorus atom with its Lewis symbol. Now, the problem was that five single dots in the Lewis symbol of the phosphorus atom (which arise from hybrid orbitals diagram) for five electrons led to the conclusion that phosphorus atom can form five bonds in a molecule, which is possible, but it is in contradiction with the octet rule the students had been learning about 15 minutes earlier. Antonia was confused, as were the students. In this case, Antonia didn't show the Knowledge of Science instructional strategies, respectively Knowledge of topic-specific teaching methods and strategies, including representations as particular examples.

Regarding the second intended learning outcome, Antonia's misunderstanding of the octet rule, expressed as: "*Students will understand the octet rule as a model used for chemical bonds formation explanation"* demonstrated by a sentence in the lesson preparation sheet, was introduced to the students as a scientific fact. This finding is consistent with Joki and Aksela (2018) conclusion based on the study on the teaching of chemical bonding using an octet rule that explanations in science education need to be promoted both before teacher education and during professional development.

Returning to Antonia's lesson on intended learning outcomes, it seems that only one of the three (*Students will understand the nature and reasons for chemical bonding formation)* has been achieved. These findings, related to RQ1, indicate that changes to the Intended learning outcomes area in Chemistry Education 2 curriculum had not been effective in Antonia's case.

Language of chemistry instruction

There were more than a few instances to demonstrate that Antonia gave proper care to the language of chemistry instruction regarding the *Chemical bonding introduction* topic. She searched for the meanings of the word *interaction* in general and in the specific context. She discussed with students about chemical bonds as interactions as well as about intermolecular interactions, asking the following questions: "*Why are interactions between atoms considered as chemical bonds, but interactions between molecules are not bonds?", "What type of change will occur if we break the interactions between atoms (chemical), and what type of change will occur if we break the interactions between molecules (physical)."* Also, she clearly stated that the octet rule is not a fact, but an artifice, principle, or model, and that covalent, ionic and metallic bonds are nothing but the models. For homework, students needed to write their own explanations of following terms: atomic radii, ionisation energy, electron affinity and relative coefficient of electronegativity. That task demonstrates Antonia's awareness the complexity and importance of concept words.

All those meaningful questions, claims, activities and representations regarding language of chemistry instruction are evidences related to RQ1 and Antonia's Knowledge of strategies for specific science topics development which is part of the Knowledge of instructional strategies (Magnusson *et al.*, 1999). Besides that, Antonia's language task could be considered as an indication of her Knowledge of assessment in Science (Chemistry), more specifically, as Knowledge of methods of assessment (Magnusson *et al.*, 1999), which refers to RQ2.

Chemical triplet

During the introduction, Antonia successfully applied her plan to connect macroscopic and sub-microscopic views of water, with focus on the properties of the substance and attractive forces between the particles and giving emphasis by announcing the title of the lesson with the sentence: "*Yes, those forces that keep atoms together we consider as chemical bonds."* We have already written about chemical triplet findings as evidence relevant to RQ1, and Antonia's Knowledge of instructional strategies (Magnusson *et al.*, 1999). The evidence of PCK described in this paragraph is an in-practice confirmation that in Antonia's case the Chemistry Education 2 curriculum redesign in the Chemical triplet area was effective.

Alternative conceptions

According to the lesson preparation sheet, Antonia was determined to recognise situations in which her students demonstrate or create alternative conceptions. We recognised that as evidence of her Knowledge of students' understanding of Science (Magnusson *et al.*, 1999) and address it to RQ1. However, beside the misconception regarding *octet rule as a model for chemical bonds formation explanation,* Antonia herself demonstrated an alternative conception, called *conservation of force* (Taber, 2003). That became obvious after she asked students why the atomic radii of different elements are smaller as we go to the right of any period of the Periodic table of elements. She agreed with a student answer that *it is because the attractive power of the nucleus is increasing too*. Finally, using the sentence "*We will* *introduce a new model which we are using to explain why chemical bonds are forming",* Antonia gave wrong meanings to Lewis symbols.

This results have shown that, beside the focus on the school student's alternative conceptions and situations which could cause them, Antonia, as well as, we speculate, other pre-service teachers, also hold alternative ideas and introduce them in practice. If they would be consistent with analysis of scientific literature about alternative conceptions (which is a part of the lesson preparation sheet) during preparation for each teaching unit, maybe they could become aware of their own misconceptions, and avoid them in future teaching situations.

The other evidences of PCK

Antonia has explained chemical bond formation with the help of the graphical and numerical simulation of change in potential energy of a two-atom system if atoms were to approach each other, and move away. The strong impression was that students fully understood why bonding occurs so it seems that the source of the knowledge (simulation) and the methods (demonstration and discussion) were selected and used successfully. Accordingly, we consider it as an evidence of Antonia's PCK domain Knowledge of the Science instructional strategies, respectively the Knowledge of strategies for specific science topic – chemical bonding, in this case. Because this evidence is not related to the areas of the Chemistry Education 2 course which were changed, but to the previous curriculum, it is addressed to RQ2.

Self-evaluation of teaching

In general, Antonia wasn't satisfied with her accomplishment. More specifically, although she was very satisfied with the working atmosphere and some students' engagement, how the simulation of change in potential energy of two atoms system helped her to lead students to understanding why bonding occurs, and how discussion of the term *interaction* contributes to students' understandings of what chemical bond is, she thought that the intended learning outcomes were only partially achieved. She said *"I think that the Octet rule is only partially adopted, and Lewis symbols are not adopted at all.* One of the problems was that she overestimated students' chemistry knowledge "*because the Gymnasium is well known in the country as one of the best if not the best"* and when Antonia fell into a problem of students' lack of Lewis symbols understanding she has missed ideas how to bring students to the outcome she has been planned to achieve. She became aware that her range of Lewis symbol examples wasn't appropriate for introducing that concepts close to the end of the class, starting with symbol of carbon atom: "*That example was given in the textbook and when I noticed that students are not following me, I have introduced examples which are also the same kind of exceptions* (she needed to mix atomic orbitals)*, and confused them even more. I should ignore what is in the textbook and give only few of the simplest examples in that moment"*, she concluded showing the growth of her PCK in domains' Knowledge of Science Learners, Knowledge about Science Curriculum and Knowledge of Science Instructional strategies (Magnusson *et al.*, 1999). That knowledge arises from in-practice topic-specific activities and could not be linked to the Antonia's enrolment in previously conducted Chemistry education courses.

Apart from the previously mentioned details, Antonia recognised other aspects of her own teaching which could be improved: "*I should insist on even more students' interaction, especially of those students who weren't active at all, my questions must be clearer and provoke higher levels of knowledge, if I realise students are not following me, I should stop* *with new content introduction and reflect what they didn't understand"*. Finally, she concluded: "*I am not satisfied, I am missing experience and creativity"*.

Antonia's self-evaluation shows numerous instances of how her PCK regarding teaching in general, and more specifically regarding teaching the *Chemical bonding introduction* for the 1st grade Gymnasium's students, has grown. This refers to Antonia's awareness of what was functioning in the classroom, and what wasn't. Some of evidences, like language item discussion is connected specifically with the revised Chemistry Education 2 curriculum, and thus, RQ1.

A very important recognition is that Antonia's PCK of chemical bonding models has been developed through the process of her teaching. That is consistent with the findings of de Jong and van Driel (2004) that opportunity for learning from teaching appeared to be an effective way for evoking the student teachers' awareness of specific teaching difficulties as well as student-learning difficulties.

Evaluation of teaching

Seven pre-service teachers evaluated Antonia's teaching. Their judgements written in free style were organised in four blocks: a) General impression of teaching, b) Good aspects of the teaching process, c) Areas of teaching which need improvement and d) The development of their own PCK. Here are interpretations from their reports.

a) Although everybody had to study Antonia's lesson preparation sheet before her teaching to become familiar with her intended learning outcomes, all of her colleagues concluded that Antonia's teaching was successful. A few of them highlighted the end of the lesson with Lewis symbols introduction as the weakest part.

b) Extracts that refer to good aspects of Antonia's teaching, which represent the most common of her colleagues' thinking, are: *example of water for chemical bonding introduction (because it enables linkage of tangible and abstract), the simulation of change in potential energy, lesson structure, clearly presented lesson's content* and *explanation of language items related to lesson,* and *communication with students.*

c) We identify a few of Antonia's colleagues' opinions regarding her teaching that suggest possible improvement:

Benita: *Introducing Lewis symbols, Antonia didn't explain why in cases of atoms of some elements, electrons should be transferred from one orbital to another, for example, in case of beryllium, but in some other cases should not, and it was a direct question of a student! That must be answered!*

Marta: Le*wis symbols should be explained much more simply. The term hybridisation should not be mentioned at all.*

Ante: *I was surprised why she has been connecting Lewis symbols with orbital and going in so deeply.*

Neda: *She should activate more students.*

d) Pre-service teachers were asked the question: "Has your knowledge about teaching of chemical bonding increased during this lesson?" Interestingly, everybody answered no. Two of them stated that it helped them to recall some chemistry concepts, like Hund's rule.

The pre-service teachers' evaluations indicate their incompetence in evaluation of teaching: nobody referred to the intended learning outcomes and whether they were achieved, and they thought that their impression was enough for judgement. However, they did recognise good aspects of teaching, some of which can be related directly to the re-designed areas of Chemistry Education 2 (water example – chemical triplet, language item discussion). Those findings strengthen our judgements about evidences of Antonia's PCK development related to RQ1.

The pre-service teachers' specific knowledge of chemistry learners' understanding is negligible: just like Antonia, they expected better chemistry students' prior knowledge. This was also the case for knowledge about the curriculum: the pre-service teachers discussed how deep Antonia should go, forgetting that Antonia followed the Gymnasium's chemistry curriculum and textbook content.

It was surprising that pre-service teachers who recognised good aspects of Antonia's teaching, as well as those ones which could be improved, think that they learned nothing about how to teach chemical bonding. We can only speculate they didn't understand the question correctly and had thought that their chemistry knowledge is questioned.

Limitations of the study

This study has limitations. One of the authors was involved in this research as a teacher of Chemistry Education courses, as well as a researcher, which could influence the reliability of the study. To ensure reliability different instruments for gathering data were conducted and all researchers were included in PCK evidences' judgement.

This study results are based on the one participant's activities so findings could not be generalised.

In this research we used the PCK model of Magnusson *et al.* (1999) to categorise PCK evidences. That is one of many PCK conceptualisations so it is possible that, according to other PCK models some of PCK evidences we have found would be categorised in different groups.

Future direction

Although preservice chemistry teachers were involved in different activities, and data was evaluated by three researchers, it is sometimes difficult to judge if some example, procedure, or other kind of teacher's treatment can be considered as evidence of PCK. Accordingly, we plan to promote this type of research, searching for school students' thinking about teaching and learning activities that work or not work for them, facing pre-service teachers with school students in interviews and/or focus groups.

Conclusion

Regarding RQ1, that component of the Chemistry Education 2 course that was re-designed for the purpose of stimulation of PCK resulted in some development of a pre-service teacher's PCK related to chemical bonding. However, a positive impact could not be connected with all re-designed areas of Chemistry Education 2 course.

In particular, no matter what instrument of gathering data has been used, evidences of Antonia's PCK of chemical bonding development in the areas of chemical triplet and language of chemistry instruction has been found. According to data gathered with the lesson preparation sheet, Antonia's self-evaluation sheet and some lesson performance' details, Antonia has demonstrated evidences which indicate a positive effect of the Chemistry Education 2 curricular changes regarding alternative conceptions related to chemical bonding.

On the other hand, Antonia did not demonstrate development of PCK regarding intended learning outcomes related to chemical bonding, especially regarding the rules of their settings indicating that changes in Chemistry Education 2 curriculum related to Intended learning outcomes didn't hit the target. However, after teaching she was fully aware of dimensions of her success in learning objective achievements.

Taking all into account we conclude that Chemistry Education 2 curriculum changes regarding Chemical triplet, Language of chemistry instruction and Alternative conceptions have had a positive impact on the development of Antonia's PCK of chemical bonding, while the curriculum's change regarding Intended learning outcomes has not.

Regarding RQ2, Antonia has demonstrated different evidences of her PCK of chemical bonding which cannot be attributed to participation in the component of the Chemistry Education 2 course re-designed to stimulate PCK, but are an outcome of the preceding components of the Chemical Education programme.

Based on PCK evidence classification into Magnusson *et al.* s' PCK domains (1999), Antonia has shown her orientation towards science teaching choosing heuristic approach for Chemical bonding introduction lesson and took into account literature based alternative conceptualisations, demonstrating an element of Knowledge of Chemistry Learners. Offering her own sequencing of teaching units, which is more sensible than the one provided in the textbook, Antonia has provided evidence of Knowledge about Chemistry Curricula. Conducting effective teaching related to two atoms' potential energy change simulation, chemical triplet representations and language of chemistry instruction activities she showed different aspects of Knowledge of Chemistry Instructional Strategies. Assigning students with specific language task for homework which corresponds with her awareness of concept words complexity Antonia indicated an element of the Knowledge of Chemistry Assessment.

Last, but not the least, Antonia's self-evaluation data showed that her PCK about chemical bonding, and, more specifically about Chemical bonding introduction teaching has been developed during in-practice activities. That cognition lights up the importance of in-practice activities in Chemistry Education programs, and consequently its importance for development of pre-service teachers' PCK.

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