A metaconceptual viewpoint in teaching about chemical bonds

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In the research of chemistry education, it has been observed that using the octet rule in teaching about chemical bonds, often causes an alternative octet framework in students. It bothers the forming of a meaningful, explanatory power and a scientifically proper understanding of chemical bonds. Metaconceptualism is a part of metacognition. Increasing metaconceptual understanding in chemistry education helps students to perceive the nature of different concepts, models and schemes, its use and boundaries. This article considers the teaching of chemical bonds from a metaconceptual point of view.

The concepts and models in chemistry are an essential part of chemistry as a science, but also of chemistry teaching and learning. When a student comes to school, he/she is not an empty board or a hard disk and neither is it possible to transfer concepts and models straight into the heads of students through a USB cable. According to a constructivist learning theory, learning is a student's active activity, where already existing conceptual structures and everyday notions included in them, are being revised. Without any points of contact to the student's existing conceptual structures, learning just becomes a meaningless way to learn by rote.

Once I had a discussion with a girl, who was on 5th grade and the daughter of a couple I know. She was preparing for her science exam. The theme in the exam, among other things, was photosynthesis. I asked the girl: What does it mean that plants such as trees produce sugar? In which part of the plant is the sugar located? She did not have answers for these questions. When a child thinks about sugar, they think of a bag of sugar in a grocery store, perhaps of icing sugar or the layer of sugar on a doughnut. Can we find a bag of sugar or even a pot of honey from inside a large oak tree – perhaps in books about Winnie the Pooh. What else could sugar have to do with for example trees or grass? The child did not know how to answer this question. At least trees or grass do not taste sweet, which is a characteristic of sugar. She had just learned by rote that plants produce sugar in photosynthesis.

Learning of concepts, and the researching of conceptual change related to that, is an essential part of research on science teaching and learning (Koponen, Rusanen, & Lappi, 2014). There are several different approaches and theoretical models in research on conceptual structures and conceptual change (Vosniadou & Ioannides, 1998; Chi, Slotta, & de Leeuw, 1994; diSessa & Sherin, 1998; Posner, Strike, Hewson, & Gertzog, 1982). The change of conceptual structures can be looked at from different viewpoints: epistemological, ontological and affective domains (Treagust and Duit, 2008).

Research on conceptual change, however, has not achieved a solid ground for theory and recently, the meaningfulness of aiming at that has been questioned. Partly, the dissimilarities between approaches originate also from the differences in the learning of concepts and conceptual change in different eras and contexts. The conceptual change of a toddler is a different phenomenon compared to the conceptual change related to learning natural science theory as a teenager (Rusanen & Pöyhönen, 2013). Conceptual change should be, if anything, seen as an umbrella term that consists of several different ways to learn, form and revise conceptual structures (Chinn & Samarapungavan, 2009).

Conceptual structures can be studied also from the systematic and dynamic viewpoints as a complex web consisting of different parts. In that case, the meaning of different parts and the connections between them in unifying conceptual structures is shaped and on the other hand, the feasibility of different explanatory models in explaining different situations (Koponen & Huttunen, 2013). The understanding of the meaning of a concept or a schema is essentially connected to concept learning. In the research of metacognitive skills, attention is paid to metaconceptual learning and teaching as one of the areas (Wiser & Amin, 2001; Yuruk, Beeth & Andersen, 2009).

Teaching about chemical bonds

Chemical bond is one of the most central concepts in chemistry. Challenges connected to its teaching and learning are, on the other hand, caused by the intangibility and its unfamiliarity in everyday understanding, but in the light of science education research, also caused by the teaching strategies (de Jong & Taber, 2014). One central problem, which is one of the most central things that hamper learning on chemical bonds and that originates from teaching, is the octet framework. The octet framework is an unjust, alternative conceptual structure that is formed for students as a result of emphasis the octet rule in teaching (Figure) (Bergqvist, Dreschler, & Rundgren, 2016; Taber, 1998).

As a consequence of octet framework, a student thinks that in chemical reactions atoms want to reach the octet. As "bonds" a student realizes only certain situations, where an electron is transferred from one atom to another or when an electron is shared between atoms, attention should be paid here especially on whose the electron has been and to whom has it been given to or shared with. As a result, the student perceives the ionic and covalent bonding as only types of bonding and thinks of the other types as only forces. As a result of octet framework, a student perceives all structures as molecules: also ionic compounds consist of molecules, because the bond is always only between atoms that have either given up or received electrons between each other. For example sodium chloride consists of NaCl molecules, where in each of them sodium has given up its electron to a specific chlorine atom and there is a bond especially between these atoms. If electric interaction is highlighted only in the case of an ionic bond, the forming of chemical bond gets social and human features easily in the student's mind: "atoms share electrons so that everyone would get a full shell (octet). No one wants to be shorthanded". Here different bonds get a different category: bonds that are based on the octet rule (ionic and covalent bonds) are actual bonds, other bonds are just forces. Later it is difficult for a student to perceive bonds that are not based on the octet rule e.g. intermolecular bonding. A dichotomic division into ionic and covalent bonds, dissolves a kind of a realism in students that almost all bonds are intermediate forms of different types of bonds and that the strength of a bond and its nature change gradually (de Jong & Taber, 2014;Taber & Coll, 2002).

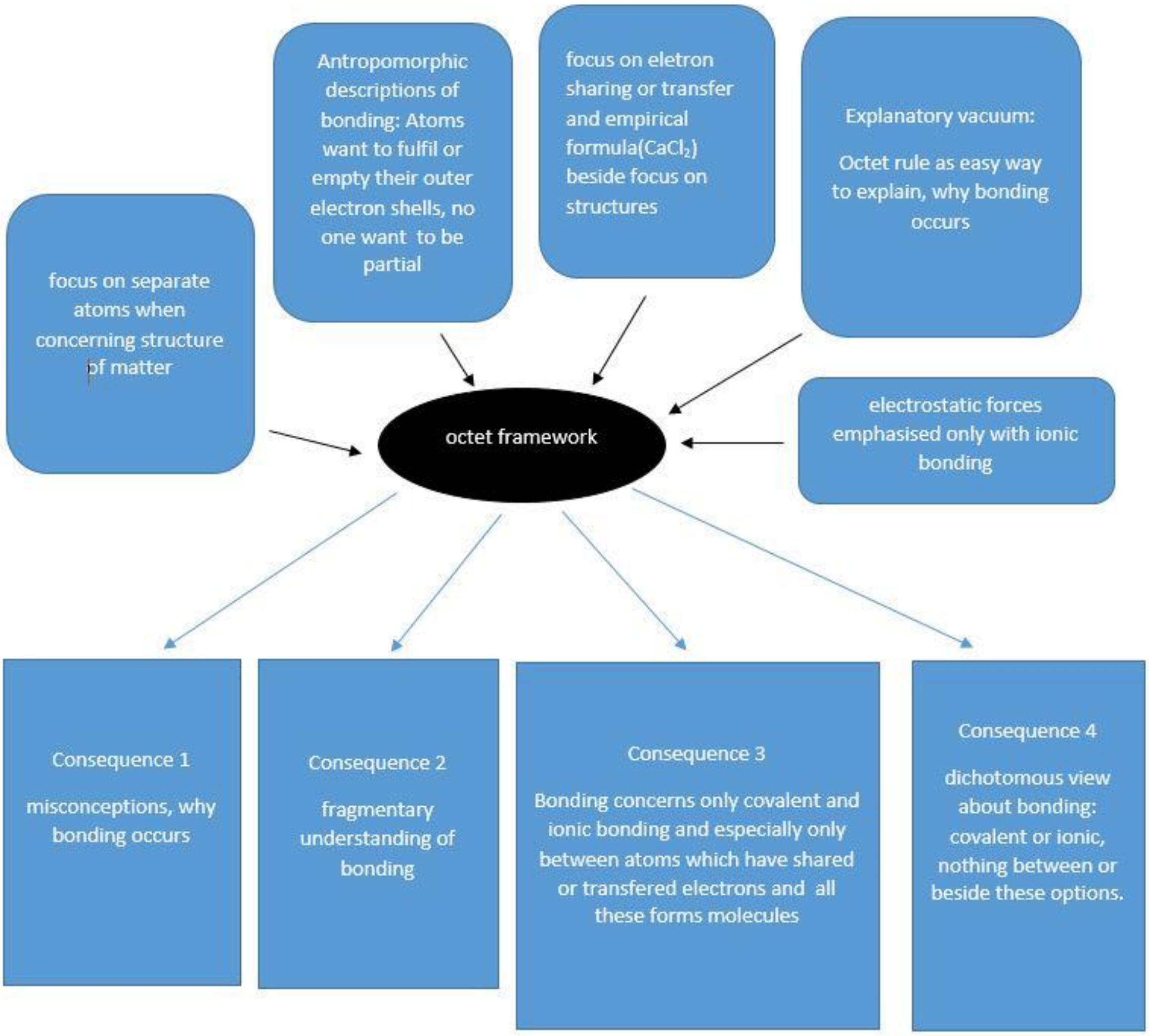

Figure. Octet framework (revised, based on Bergqvist et al. 2016)

Based on a research (Asunta & Joki, 2003), a teaching model on chemical bonds has been developed during teaching post. The developed teaching model emphasises electric interaction as a common basis of all bonding types and different types of bonds are handled at the same time, being compared with each other. In the first part of the research, students' conceptual structures produced by a teaching model were studied in the final stage of middle school. The conceptual structures were analyzed from a systemic point of view, which helped in perceiving the meaning of different parts such as concepts, mnemonics and explaining schemes, in the whole and on the other hand their usage in different problem-solving situations (Joki, Lavonen, Juuti, & Aksela, 2015). In the discussion paragraph in the first part of research it was presented that if electric interaction as the common basis of chemical bonding and as an explanatory schema is brought out clearly, then it is possible to perhaps use a full shell principle or the octet rule as a mnemonic device later, as long as its role as just a mnemonic – and not as explaining schema and as a factor that causes bonds or reactions – is made clear to the students (Joki, Lavonen, Juuti, & Aksela, 2015).

In the second part of my research, a part in the making, it is looked at how the conceptual structures of the students, whom I have researched, develop during the first year of high school. In addition, the purpose is to find out how teachers perceive the meaning of the octet rule – is it more like a mnemonic to them than an explaining schema and how does this teacher's metaconceptual understanding affect the student's understanding. At the same time, the teaching model of chemical bonding, based on the observations and ideas acquired from the research, is developed further. In a Winnie the Pooh story, Rabbit said: "We are going to figure this thing out root and branch (thoroughly)!" Piglet nodded, even though he did not understand what it had to do with roots.

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